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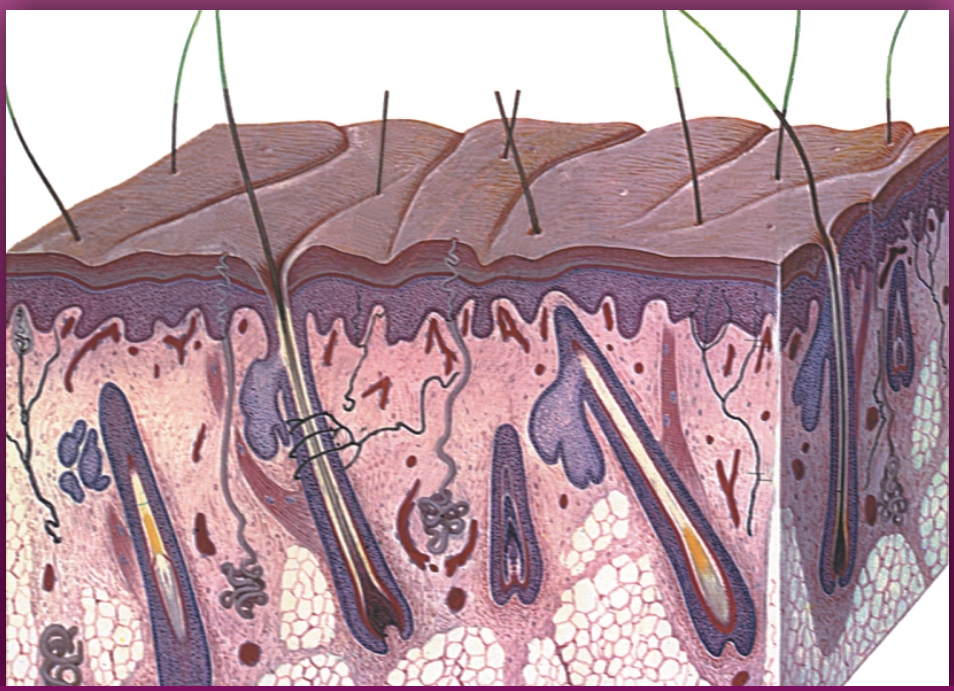
A Textbook of Human Physiology



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Human Physiology

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Preface

Why another book on Human Physiology? At the graduate level students get lost in a sea of jargons. Questions easily answered by someone experienced in the field send students scouting for information into a veritable library of books and articles to get a simple answer. To arouse interest and sustain the attention of the students, the need to make physiology interesting and simpler was felt. With this idea, the book was conceived and is a part of our effort to give the students information at the tip of their fingers. Rich inputs of our own teaching experience for more than a decade, we hope will to give the students an easier time. It introduces physiology at an introductory level while providing a useful insight into the nature and function of the human body. Our desire to write this book was to reach out to a large number of the student community and help them understand the subject. It is hoped that this introductory text in a simple language and lucid style caters to the needs of Para-medical and the Life-science students apart from the general stream at whom the book primarily aims at.

H.S. Ravikumar Patil
H.K. Makari
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CHAPTER 1

Skeletal System

"Skeleton forms a framework
It assists one to work
Is a profound network
Even auto mend if meets a jerk"

1.1 INTRODUCTION

Skeletal system consists of all the bones in the body and the tissues such as tendons, ligament and cartilage that connect them. Teeth are also considered part of skeletal system but they are not counted as bones. Teeth are made of enamel and dentin. Enamel is the strongest substance in the body.

A skeleton is a sturdy framework of about 206 bones that protects the organs, supports the body, provides attachment points for muscles to enable body movement, functions as a storage site for minerals such as calcium and phosphorus, and produces blood cells.

The skeletal system is a living, dynamic system, with networks of infiltrating blood vessels. Living mature bone is about 60% calcium compounds and 40% collagen. Hence, bone is strong, hard and slightly elastic. All humans are born with over 300 bones, but some bones, such as those in the skull and lower spine, fuse during growth, thereby reducing the number. Although mature bones consist largely of calcium, most bones in the skeleton of

vertebrates, including humans, began as cartilage. Some animals, such as sharks and sting rays retain their cartilaginous skeleton in adulthood. Cartilage is a type of connective tissue and contains collagen and elastin fibers.

Individual bones meet at areas called joints and are held in place by connective tissues. Most joints, such as the elbow are called synovial joints for the synovial membrane which envelopes the joint and secretes a lubricating fluid. Cartilage lines the surface of many joints and helps reduce friction between bones. The connective tissues linking the skeleton together at the joints are tendons and ligaments. Ligaments and tendons are both made up of collagen, but serve different functions. Ligaments link bones together and help prevent dislocated joints. Tendons link bone to muscle.

Since the bones that make up the human skeleton are inside the body, the skeleton is called an endoskeleton. Some animals such as the crab, have an external skeleton called an exoskeleton.

1.2 FUNCTIONS OF SKELETAL SYSTEM

A) Support

Skeletal system protects and supports the body. Heart and lungs are shielded by ribs, spinal cord is protected by vertebral column, and brain is protected by skull. It also supports the softer tissues and provides points of attachment for most skeletal muscles.

B) Storage

Bones store minerals such as calcium, phosphorus and release them into the surrounding tissues to help the nerves and muscles function properly. Also, when required, bone releases minerals into the blood, facilitating the balance of minerals in the body. The cavities inside the arm and leg bones also store fat that can be used for energy.

C) Assisting Movement

Skeletal muscles, which are attached to the bones by tendons pull on the bones. Therefore when the associated muscles contract, they cause bones to move without bones, man would not be able to sit, stand, walk or run.

D) Blood Cell Formation

Red marrow found in the spongy bone of legs, arms, ribs, sternum (breastbone), and vertebrae (backbones) makes red and white blood cells.

E) Storage of Chemical Energy

With the increasing age, some bone marrow changes from 'red bone marrow' to

'yellow bone marrow'. Yellow bone marrow consists mainly of adipose cells and few blood cells. It is an important chemical energy reserve.

1.3 STRUCTURE OF SKELETAL SYSTEM

The human skeletal system is divided in two main groups: the *axial skeleton* and the *appendicular skeleton*. The axial skeleton includes bones associated with the main axis of the body—the spine. This includes the spine and the skull and rib cage which are connected to the spine. The appendicular skeleton is attached to the axial skeleton and consists of the bones associated with the appendages of the body—the arms and legs. This includes the bones of the pectoral girdle or shoulder area, bones of the pelvic girdle or hip area, arm and leg bones.

A) Axial Skeleton

The axial skeleton consists of the skull, vertebral column, ribs and the sternum. Together the bones forming these structures constitute the central bony core of the body, the axis.

There are 28 bones in the skull. Of these, 8 bones comprise the cranium and provide protection for the brain. In adults, these bones are flat and interlocking at their joints, thus making the cranium immobile. Fibrous joints or sutures occur where the bony plates of the cranium meet and interlock. Cartilage filled spaces between the cranial bones of infants known as soft spots or fontanelles, allow their skull bones to move slightly during birth. This makes birth easier and helps prevent skull fractures, but may leave the infant with an odd-shaped head temporarily while the skull regains its shape. Eventually, the fontanelles in an infant's head are replaced by bone and fibrous joints develop. In addition to protection, skull bones also support and protect the sensory organs responsible for sight, hearing, smell and taste.

The eight bones of the cranium are: frontal, parietal (2), temporal (2), ethmoid, sphenoid and occipital. Fourteen bones shape the cheeks, eyes, nose and mouth. These include the nasal (2), zygomatic (2), maxillae (2), and the mandible. The upper, bony bridge of the nose is formed by the nasal bones and provides an attachment site for the cartilage making up the softer part of the nose. Located behind these facial bones are other bones which shape the interior portions of the eyes, nose and mouth. These are the lacrimal (2), palatine (2), conchae (2), and vomer bones. In addition to these 28 skull bones is the hyoid bone, located at the base of the tongue. Technically, the hyoid bone is not part of the skull but it is often included with the skull bones. It provides an attachment site for the tongue and some neck muscles.

The skull rests atop of the spine, which encases and protects the spinal cord. The spine also called the vertebral column or backbone, consists of 33 stacked vertebrae

with the lower ones fused. There are seven cervical, or necks, vertebrae. Below the cervical vertebrae are the 12 thoracic, or upper back, vertebrae. The ribs are attached to these vertebrae. Thoracic vertebrae are followed by five lumbar, or lower back, vertebrae. Last is the sacrum composed of five fused vertebrae and the coccyx or tail bone, composed of four fused bones. The vertebral column helps to support the weight of the body and protects the spinal cord. A pair of ribs extends forward from each of the 12 thoracic vertebrae, for a total of 24 ribs. Occasionally, a person is born with an extra set of ribs. The flat bone called sternum can be felt just under the skin in the middle of the chest.

Skull bones

The skull rests on the upper end of the vertebral column and its bony structure is divided into two parts: The *cranium* and the *face*. The Human cranium and facial bones are the foundation for the soft tissues of the face and head. Thus, much of the visible appearance of the human face depends upon the shapes and qualities of these bones.

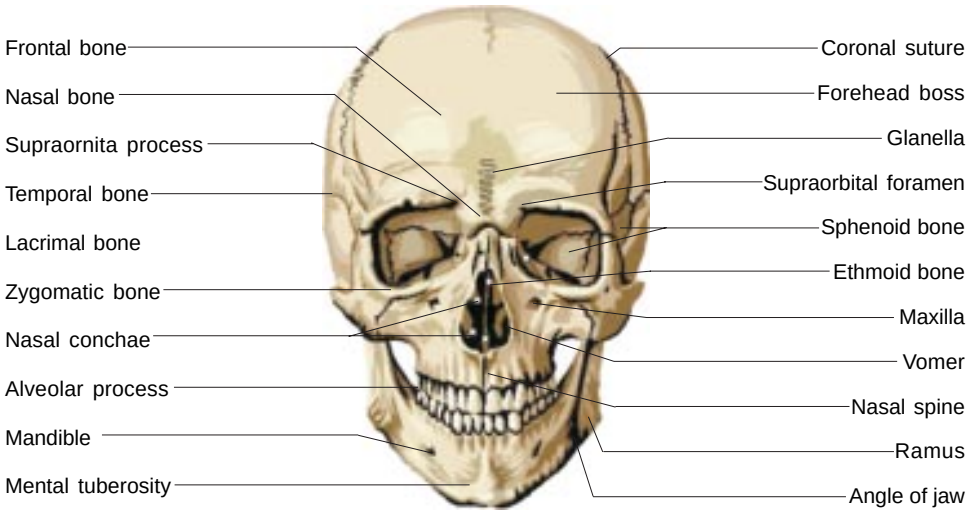


Fig. 1.1: Diagram of skull bones.

Cranium

The cranium is that part of the skull that holds and protects the brain in a large cavity, called the cranial vault. Eight plate-like bones form the human cranium by fitting together at joints called sutures. The most important of these cranial bones for the appearance of the face is the frontal bone, which underneath the top of the face above

the eyeballs. It is made-up of a number of flat and irregular bones. It has a base upon which the brain rests and a vault that surrounds it. The peritoneum lining the inner surface of the skull bones forms the outer layer of dura mater. In the mature skull, the joints(sutures) between the bones are immovable(fibrous). The bones have numerous perforations (e.g. foramina, fissures) through which nerves, blood and lymph vessels pass. The bones of the cranium are:

1. 1 frontal bone
2. 2 parietal bones
3. 2 temporal bones
4. 1 occipital bone
5. 1 sphenoid bone
6. 1 ethmoid bone

Frontal bone: This is the bone of the forehead and forms the eyebrow. It forms part of the orbital cavities (eye sockets) and the prominent ridges above the eyes, the supraorbital margins. Just above the supraorbital margins, within the bone, are two air filled cavities or sinuses lined.

1. Occipital bone
2. Lambdoid suture
3. Parietal bone
4. Sagittal suture
5. Coronal suture
6. Frontal bone

Parietal bones: These bones form the sides and roof of the skull. They articulate with each other at the sagittal suture, with the frontal bone at the coronal suture and the occipital bone at the squamous sutures. The inner surface is concave and grooved by the brain and blood vessels.

Temporal bones: The temporal bones are located behind the eyes. Each temporal bone encloses the cochlea and labyrinth of the inner ear and the ossicles, three tiny bones of the middle ear, which are not part of the cranium. These bones lie one on each side of the head and form fibrous immovable joints with the parietal, occipital, sphenoid and zygomatic bones.

Occipital bone: This bone forms the back of the head and part of the base of the skull. It has immovable fibrous joints with the parietal, temporal and sphenoid bones. Its inner surface is deeply concave and concavity is occupied by the occipital lobes of the cerebrum and the cerebellum.

Sphenoid bone: This bone occupies the middle portion of the base of the skull and it articulates with the occipital, temporal, parietal and frontal bones. It links the cranial and facial bones, and cross braces the skull.

Ethmoid bone: The ethmoid bone occupies the anterior part of the base of the skull and helps to form the orbital cavity, the nasal septum and the lateral walls of the nasal cavity. It is a very delicate bone containing many air sinuses lined with ciliated epithelium and with openings into the nasal cavity.

Face

The facial skeleton consists of 14 stationary bones and a mobile lower jawbone (mandible). These 14 bones form the basic shape of the face, and are responsible for providing attachments for muscles that make the jaw move and control facial expressions.

1. 2 zygomatic(cheek) bones
2. 1 maxilla(originated as 2)
3. 2 nasal bones
4. 1 vomer
5. 2 palatine bones
6. 2 inferior conchae
7. 1 mandible(originated as 2)

Zygomatic (cheek) bones: These bones form the prominences of the cheeks and part of the floor and lateral walls of the orbital cavities.

Maxilla (upper jaw bone): This originates as two bones, but fusion takes place before birth. The maxilla forms the upper jaw, the anterior part of the roof of the mouth, the lateral walls of the nasal cavity and part of the floor of the orbital cavities.

Nasal bones: These are two small flat bones that form the greater part of the lateral and superior surfaces of the bridge of the nose.

Lacrimal bones: These two small bones are posterior and lateral to the nasal bones and form part of the medial walls of the orbital cavities.

Vomer: This is a thin flat bone that extends upwards from the middle of the hard palate to form most of the inferior part of the nasal septum. Superiorly it articulates with the perpendicular plate of the ethmoid bone.

Palatine bones: These are the small L-shaped bones. The horizontal parts unite to form the posterior part of the hard palate, and perpendicular parts project upwards to form part of the lateral walls of the nasal cavity. At their upper extremities they form part of the orbital cavities.

Inferior conchae: Each conchae is a scroll-shaped bone, which forms the part of the lateral wall of the nasal cavity and projects into it below the middle concha. The conchae collectively increase the surface area of the nasal cavity, allowing the inspired air to be warmed and humidified more effectively.

Mandible: This is the lower jaw, the only movable bone of the skull. It originates as two parts that unite at the midline.

Hyoid bone: This is an isolated horseshoe-shaped bone lying in the soft tissues of the neck just above the larynx and below the mandible. It does not articulate with any other bone. It supports the larynx and gives attachment to the base of the tongue.

Sinuses: Sinuses containing air are present in the sphenoid, ethmoid, maxillary and frontal bone. They all communicate with nasal cavity and are lined with ciliated mucous membrane. Their functions are to give resonance to the voice and to reduce the weight of the skull, making it easier to carry.

Fontanelles of the skull: At birth, ossification of the cranial sutures is incomplete. Fontanelles are distinct membraneous area where three or more bones meet. The two largest are the anterior fontanelle, not fully ossified until the child is 12 to 18 months-old. The posterior fontanelle is usually ossified 2 to 3 months after birth. The skull bones do not fuse earlier to allow for moulding of the baby's head during child birth.

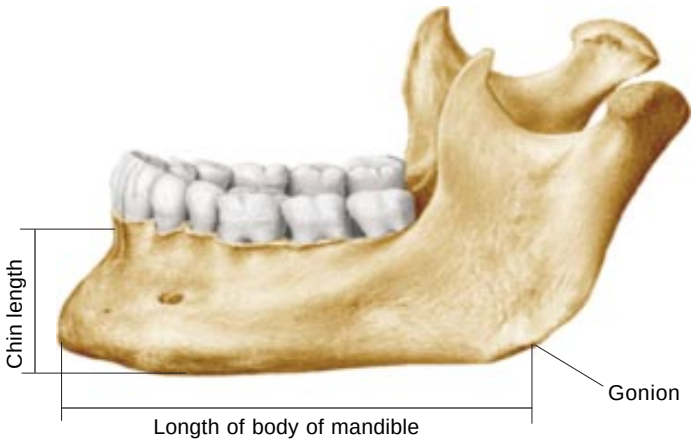


Fig. 1.2: Fontanelle of Skull.

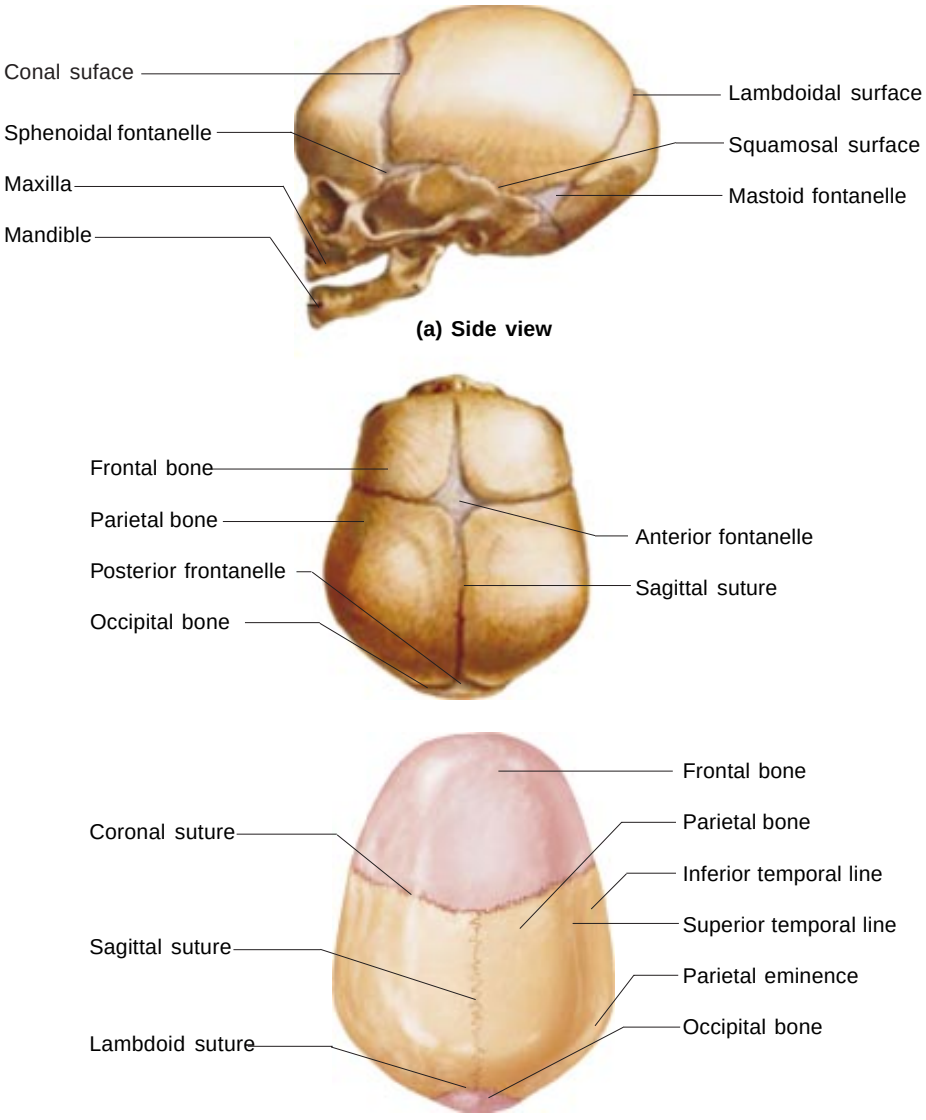


Fig. 1.3: (a) Side view and (b) Top view of skull.

Vertebral column

The spinal column (or vertebral column) extends from the skull to the pelvis and is made up of 33 individual bones termed vertebrae. The vertebrae are stacked on top of each other group into four regions. The first seven vertebrae, in the neck, form the cervical spine; the next twelve vertebrae are the thoracic spine and the next five the lumbar spine, the lowest vertebra of which articulates with the sacrum. Each vertebra

is identified by the first letter of its region in the spine, followed by a number indicating its position, which is shown in the following table (Table 1.1).

Table. 1.1

Term	No. of Vertebrae	Body Area	Abbreviation
Cervical	7	Neck	C1 - C7
Thoracic	12	Chest	T1 - T12
Lumbar	5 or 6	Low Back	L1 - L5
Sacrum	5 (fused)	Pelvis	S1 - S5
Coccyx	3	Tailbone	None

The cervical spine is further divided into two parts: the upper cervical region (C1 and C2), and the lower cervical region (C3 through C7). C1 is termed the Atlas and C2 the Axis. The Occiput (CO), also known as the Occipital Bone, is a flat bone that forms the back of the head.

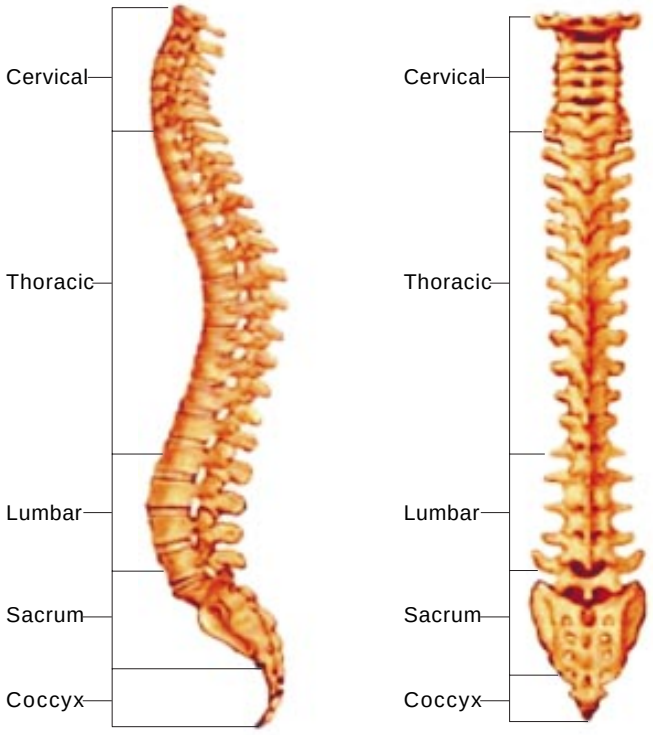


Fig.1.4: Vertebral column.

General characteristics of a vertebra

A typical vertebra consists of two essential parts viz., an anterior segment, the body, and a posterior part, the vertebral or neural arch; these enclose a foramen, the vertebral foramen. The vertebral arch consists of a pair of pedicles and a pair of laminae, and supports seven processes viz., four articular, two transverse, and one spinous.

When the vertebrae are articulated with each other, the bodies form a strong pillar for the support of the head and trunk, and the vertebral foramina constitute a canal for the protection of the medulla spinalis (spinal cord), while between every pair of vertebrae are two apertures, the intervertebral foramina, one on either side, for the transmission of the spinal nerves and vessels.

Body (corpus vertebrae): The body is the largest part of a vertebra, and is more or less cylindrical in shape. Its upper and lower surfaces are flattened and rough, and give attachment to the intervertebral fibrocartilages, and each presents a rim around its circumference. In front, the body is convex from side to side, and concave from above downward. Behind, it is flat from above downward and slightly concave from side to side. Its anterior surface presents a few small apertures, for the passage of nutrient vessels; on the posterior surface is a single large, irregular aperture, or occasionally more than one, for the exit of the basi-vertebral veins from the body of the vertebra.

Pedicles (radices arci vertebrae): The pedicles are two short, thick processes, which project backward, one on either side, from the upper part of the body, at the junction of its posterior and lateral surfaces. The concavities above and below the pedicles are called the vertebral notches and when the vertebrae are articulated, the notches of each contiguous pair of bones form the intervertebral foramina, already referred to.

Laminae: The laminae are two broad plates directed backward and medial ward from the pedicles. They fuse in the middle line posteriorly, and complete the posterior boundary of the vertebral foramen. Their upper borders and the lower parts of their anterior surfaces are rough for the attachment of the ligamenta flava.

Spinous process: The spinous process is directed backward and downward from the junction of the laminae, and serves for the attachment of muscles and ligaments.

Articular processes: The articular processes, two superior and two inferior, spring from the junctions of the pedicles and laminae. The superior project upward, and their articular surfaces are directed more or less backward. The inferior project downward and their surfaces look more or less forward. The articular surfaces are coated with hyaline cartilage.

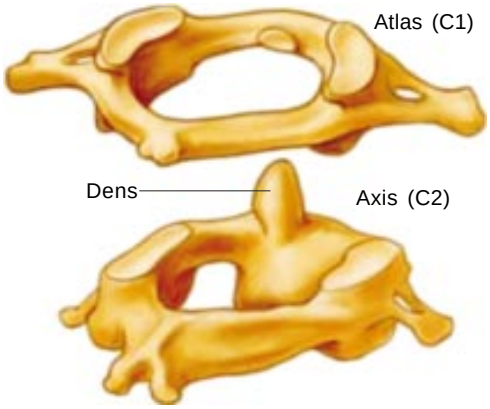
Transverse processes (processus transversi): The transverse processes, two in number, project one at either side from the point where the lamina joins the pedicle, between the superior and inferior articular processes. They serve for the attachment of muscle and ligaments.

Characteristics of prominent vertebral regions

Cervical vertebrae: The first seven vertebrae are called the cervical vertebrae. Located at the top of the spinal column, these bones form a flexible framework for the neck and support the head. The first cervical vertebra is called the atlas and the second is called the axis. The atlas' shape allows the head to nod "yes" and the axis' shape allows the head to shake "no".

Atlas (C1)

The Atlas is the first cervical vertebra and therefore abbreviated C1. This vertebra supports the skull. Its appearance is different from the other spinal vertebrae. The atlas is a ring of bone made up of two lateral masses joined at the front and back by the anterior arch and the posterior arch.



Axis (C2)

The Axis is the second cervical vertebra or C2. It is a blunt tooth-like process that projects upward. It is also referred to as the 'dens' (Latin for 'tooth') or odontoid process. The dens provide a type of pivot and collar allowing the head and atlas to rotate around the dens.

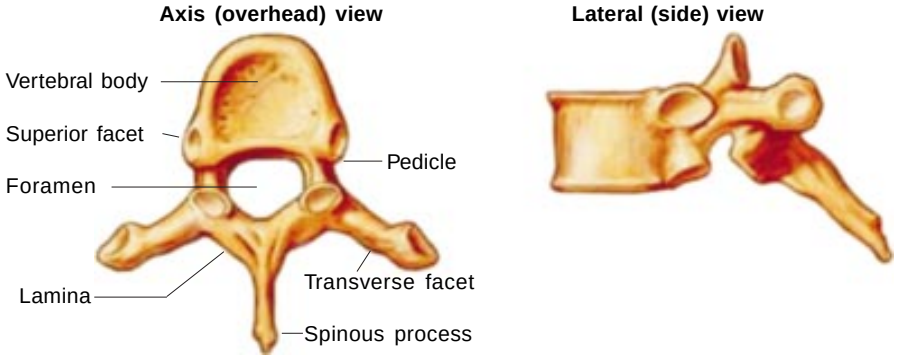


Fig. 1.5: Diagram showing axis overhead and side view.

Thoracic vertebrae (T1 - T12)

The thoracic vertebrae increase in size from T1 through T12. They are characterized by small pedicles, long spinous processes, and relatively large intervertebral foramen (neural passageways), which result in less incidence of nerve compression.

The rib cage is joined to the thoracic vertebrae. At T11 and T12, the ribs do not attach, so they are called "floating ribs." The thoracic spine's range of motion is limited due to many rib/vertebrae connections and the long spinous processes.

Fig. 1.6: Posterior (back) view thoracic spine and rib cage.

Lumbar vertebrae (L1 - L5)

The lumbar vertebrae graduate in size from L1 through L5. These vertebrae bear much of the body's weight and related biomechanical stress. The pedicles are longer and wider than those in the thoracic spine. The spinous processes are horizontal and

more squared in shape. The intervertebral foramen (neural passageways) is relatively large but nerve root compression is more common than in the thoracic spine.

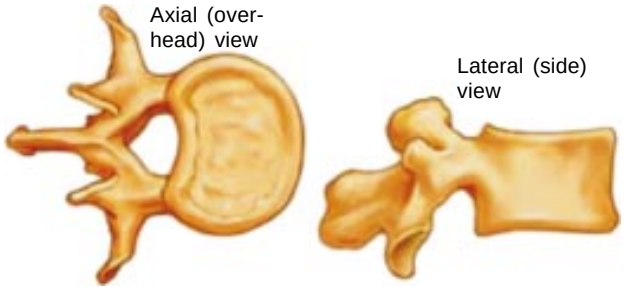


Fig.1.7: Lumbar vertebrae.

Purpose of the vertebrae

Although vertebrae range in size—cervical the smallest, lumbar the largest—vertebral bodies are the weight bearing structures of the spinal column. Upper body weight is distributed through the spine to the sacrum and pelvis. The natural curves in the spine, provide resistance and elasticity in distributing body weight and axial loads sustained during movement.

The vertebrae are composed of many elements that are critical to the overall function of the spine, which include the intervertebral discs and facet joints.

Table 1.2: Functions of the vertebral or spinal column.

Protection	• Spinal cord and nerve roots • Many internal organs
Base for attachment	• Ligaments • Tendons • Muscles
Structural support	• Head, shoulders, chest • Connects upper and lower body • Balance and weight distribution
Flexibility and mobility	• Flexion (forward bending) • Extension (backward bending) • Side bending (left and right) • Rotation (left and right) • Combination of above
Other	• Bones produce red blood cells • Mineral storage

In addition to allowing humans to stand upright and maintain their balance, the vertebral column serves several other important functions. It helps to support the head and arms, while permitting freedom of movement. It also provides attachment for many muscles, the ribs, and some of the organs and protects the spinal cord, which controls most bodily functions.

Rib cage

The rib cage, shaped in a mild cone shape and more flexible than most bone sets, is made up of varying elements such as the thoracic vertebra, 12 equally paired ribs, costal cartilage, and held together anteriorly by the sternum (Fig.1.8). The primary responsibility of the rib cage involves protecting the thoracic visceral organs, enclosing the thoracic visceral organs, and is included in the general mechanics of the process of breathing. The construction of rib cage involves the compression and narrowing of the anterior as well as the superior angles, while it widens as it travels down the body. It provides structural support for the upper extremities as well as the pectoral girdle. There are specified bones within the rib cage that are responsible for the production of red blood cells from the active bone marrow.

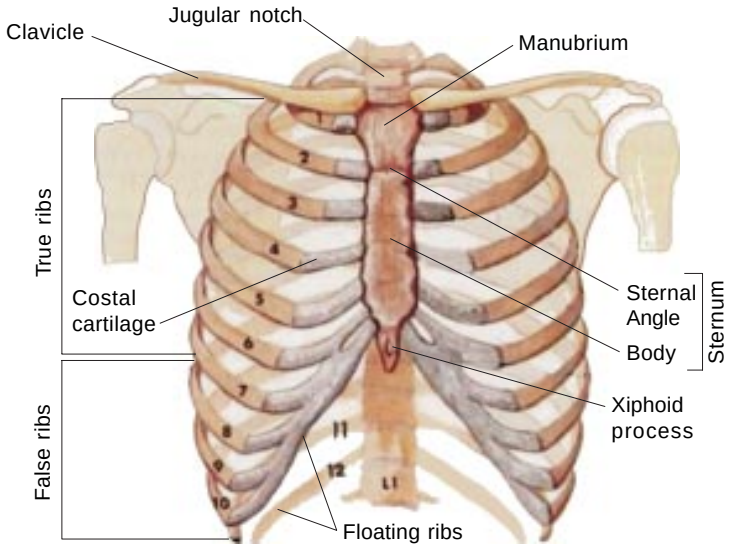


Fig. 1.8: The rib cage.

The sternum

The sternum is the long and **flat bone** structure that is actually a plate consisting of 3 separate bones. Consisting of the **upper manubrium,** the central body, and the **lower xiphoid** process, the sternum creates an anchor for the ribs meeting centrally at the midline of the body. The xiphoid process is typically made up of cartilage Fig. 1.9.

The costal cartilage of the first and second ribs meets with the manubrium. The second through the tenth ribs meet with the body of the sternum via costal cartilage. The xiphoid process is available for muscle attachment and does not adhere to the ribs. The costal margin of the rib cage is formed by the fusion of the eight, ninth, and tenth ribs' coastal cartilage where the two opposing costal margins meet at the xiphoid process. Costal angle is the region between the body of the sternum and the manubrium, and even with the second rib the sternal angle, also known as the angle of Louis, can be found. The 3 primary angles, the costal angle, the sternal angle, and the costal margins are landmarks when determining positional suitability concerning the thorax and the abdomen.

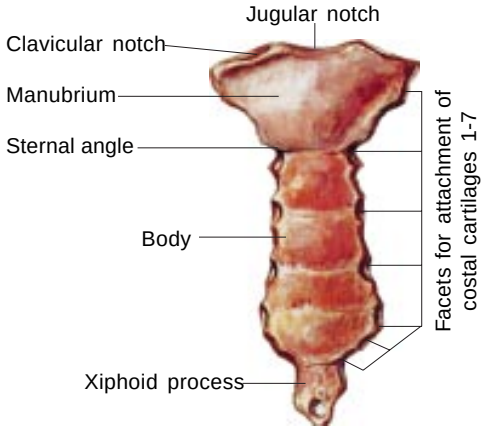
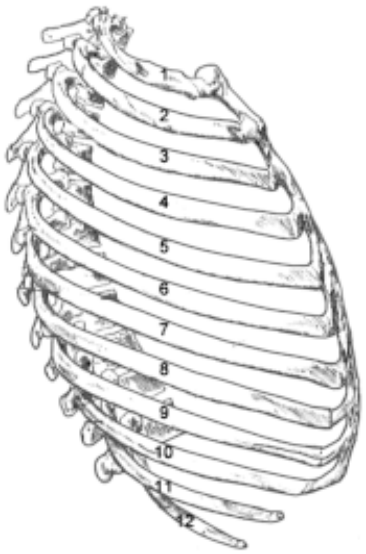


Fig. 1.9: The sternum.

The Ribs

The twelve pairs of ribs, which are embedded within the walls of the muscular structures, attach in the posterior to a thoracic vertebra. The first 7 pairs use the sternum as their anchor via the rib's individual costal cartilage as an attachment vessel. The first 7 pairs are also called true ribs. Ribs (8 through 12) are deemed as false ribs. The remaining 2 pairs of ribs are considered floating ribs as there is no attachment to the sternum at all. True ribs connect directly to the sternum while false ribs are connected to the sternum via additional bone structures, and floating ribs do not connect to the sternum.

Ribs do vary structurally, although the top ten pairs of ribs come equipped with a head and a tubercle for attachment to the **vertebrates**. The final two pairs are equipped with a head but are lacking a tubercle. All twelve pairs have a **neck, angle,** and a **body.** The head of each rib is designed to project posteriorly and joins with the body of the corresponding thoracic vertebra. The tubercle is knobby in appearance and resides just laterally of the head. It joins with the facet on the transverse process of



the thoracic vertebra. The constricted area that is designed between the head and the tubercle is known as the neck. The main portion of the rib is curved to give structural support to the body. The costal groove is designed to protect the costal nerve and its corresponding vessels. The intercostal muscles take up the space between the ribs, which have been deemed as the intercostal spaces.

B) Appendicular Skeleton

The appendicular skeleton joins with the axial skeleton at the shoulders and hips. Forming a loose attachment with the sternum is the **pectoral girdle**, or **shoulder**. Two bones, the **clavicle** (collar bone) and scapula (shoulder blade) form one shoulder. The **scapula** rest on top of the ribs in the back of the body. Unlike the pectoral girdle, the **pelvic girdle,** or **hips,** is strong and dense. Each hip, left and right, consists of three fused bones, the ilium, ischium and pubic. Collectively, these three bones are known as the innominate bone. The innominates fuse with the sacrum to form the pelvic girdle. In addition, the pelvic girdle of women is generally wider than that of men. This also helps to facilitate birth, but is a slight impediment for walking and running. Hence, men, with their narrower hips, are better adapted for such activities. The **arms** and **legs,** appendages of the body, attach to the girdle, pectoral or pelvic, via a ball and socket joint, a special type of synovial joint.

Shoulder girdle

Usually, a "**girdle**" refers to something that encircles or is a complete ring. However, the shoulder girdle is an incomplete ring. In the front, the clavicles are separated by the **sternum**. In the back, there is a gap between the two scapulae. The Shoulder

Girdle, also called the **Pectoral girdle**, is composed of four bones: two **clavicles** and two **scapula**.

Clavicle (collar bone)

The clavicle, commonly called the collar bone, is a slender S-shaped long bone that connects the upper arm to the trunk of the body and holds the shoulder joint away from the body to allow for greater freedom of movement. One end of the clavicle is connected to the sternum and the other end is connected to the scapula. The clavicle provides the only bony link between the upper limb and the axial skeleton.

Scapula (shoulder blade)

The scapula is a large, triangular, flat bone on the back side of the rib cage commonly called the shoulder blade. It lies on the posterior chest wall superficial to the ribs overlays the second through seventh rib and serves as an attachment for several muscles. It has a shallow depression called the glenoid cavity that the head of the humerus (upper arm bone) fits into.

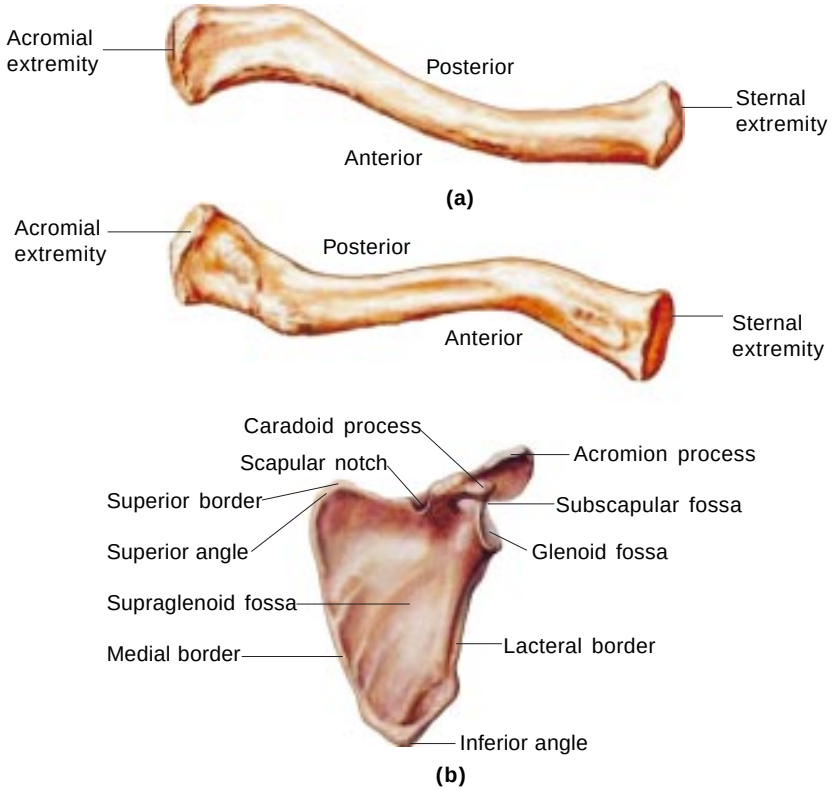


Fig.1.10: Scapula (a) Superior surface (b) Inferior surface

On the posterior surface runs the rough ridge called the spine, which extends beyond the lateral border of the scapula and overhangs the glenoid cavity. The prominent overhung, which can be felt through the skin as the highest point of the shoulder, is called acromial process and forms the joint with the clavicle— the acromioclavicular joint— a slightly movable synovial joint that contributes to the mobility of the shoulder girdle. The caradoid process, a projection from the upper border of the bone, gives attachment to the muscles to move.

1.4 UPPER LIMB

In human anatomy, the upper limb (also upper extremity) refers to what in common English is known as the arm, i.e., the region of the shoulder to the fingertips. It includes the entire limb, and thus, is not synonymous with the term "upper arm".

This contains the bones of the superior appendicular skeleton.

1. The clavicle and scapula (pectoral girdle)
2. Humerus (arm)
3. Ulna and radius (forearm)
4. Carpal bones (wrist)
5. Metacarpals (hand)
6. Phalanges (fingers).

Humerus

This is the bone of the upper arm. It is the largest bone of the upper limb. Its smooth ball-like head articulates with the glenoid fossa of the scapula, forming a shoulder joint. Distal to the head are two roughened projections of bone, the greater and lesser tubercles, and between them there is a deep groove, the bicipital groove or intertubercular sulcus, occupied by one of the tendons of the biceps muscle.

The distal end of the bone presents two surfaces that articulate with the radius and ulna to form the elbow joint.

Ulna and Radius

These are the two bones of the forearm. The ulna is longer than and medial to the radius, and when arm is in anatomical position, i.e., with the palm of the hand facing forward, the two bones are parallel. They articulate with the humerus at the elbow joint, the carpel bones at the wrist joint, and with each other at the proximal and distal radioulnar joints. In addition, an interosseous membrane, a fibrous joint, connects the bones along their shafts, stabilizing their association and maintaining their relative positions despite forces applied from the elbow or wrist.

Carpal (Wrist) Bones

There are eight carpal bones arranged in two rows of four. From outside inwards they are:

1. Proximal row: scaphoid, lunate,triquetral, pisiform
2. Distal row: Trapezium, trapezoid, captate,hamate.

These bones are closely fitted together and held in a position by ligaments that allow a limited amount of movement between them.

Metacarpal Bones (Bones of the hand)

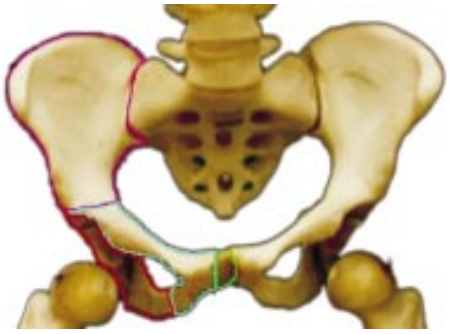
These five bones form the palm of the hand. They are numbered from thumb side inwards. The proximal ends articulate with the carpal bones and distal ends with the phalanges.

Phalanges (Finger bones)

There are 14 phalanges, three in each finger and two in the thumb. They articulate with the metacarpal bones and with each other, and other by hinge joints.

Pelvic Girdle

The pelvic girdle, also called the hip girdle, is composed of two coxal (hip) bones. The coxal bones are also called the ossa coxae or innominate bones. During childhood, each coxal bone consists of three separate parts: the ilium, the ischium, and the pubis. In an adult, these three bones are firmly fused into a single bone. In the picture below, the coxal bone on the left side has been divided into its component pieces while the right side has been preserved.



At the back, these two bones meet on either side of the sacrum. In the front, they are connected by a muscle called the pubic symphysis.

The pelvic girdle serves several important functions in the body. It supports the weight of the body from the vertebral column. It also protects and supports the lower organs,

including the urinary bladder, the reproductive organs, and the developing fetus in a pregnant woman.

The pelvic girdle differs between a man and a woman. In a man, the pelvis is more massive and the iliac crests are closer together. In a woman, the pelvis is more delicate and the iliac crests are farther apart. These differences reflect the woman's role in pregnancy and delivery of children. When a child is born, it must pass through its mother's pelvis. If the opening is too small, a cesarean section may be necessary.

The pelvis

The pelvis is formed by hip bones, the sacrum and the coccyx. It is divided into upper and lower parts by the brim of the pelvis, consisting of the promontory of the sacrum and the iliopectineal lines of the innominate bones. The greater or false pelvis is above the brim and lesser or true pelvis is below.

Lower Limbs

These are appendages attached at the pelvic(hip) girdle, consisting of the thigh, knee, leg, ankle, foot and toes. These are also called **lower extremity.** It has 30 bones in four locations – (1) Femur in thigh; (2) The patella (Kneecap); (3) the Tibia in the leg; (4) and the seven tarsals in the ankle, the 5 metatarsals in the metatarsus and the 14 phalanges (bones of the digits) in the foot.

Femur

The femur or the thigh bone is the longest, heaviest and the strongest bone in the body. Its proximal end articulates with the acetabulum of the hip bone. Its distal end articulates with the tibia and patella. The body (shaft) of the femur angles medially and as a the knee joints are closer to the midline. The angle of convergence is greater in females because the female pelvis is broader.

Patella

The patella (= little dish), or kneecap, is a small, triangular bone located anterior to the knee joint. It is a sesamoid bone that develops in the tendon of the quadriceps femoris muscle. The broad superior end of the patella is called the base. The pointed interior end is the apex. The posterior surface contains two articular facets, one for the medial condyle and the other for the later condyle of the femur.

Tibia and Fibula

The tibia or shin bone is larger, medial, weight bearing bone of the leg. The tibia articulates at its proximal end with the femur and fibula, and at its distal end with the

fibula and the talus bone of the ankle. An interosseus membrane connects the tibia and fibula.

The proximal end of the tibia is expanded into lateral condyle and medial condyle. These articulate with the condyles of the femur to form the lateral and medial tibiofemoral (knee) joints.

The fibula is parallel and lateral to the tibia, but is considerably smaller than the tibia. The proximal end, the head of the fibula, articulates with the interior surface of the lateral condyle of the tibia below the level of the knee joint to form the proximal tibiofubular joint. As noted, the fibula also articulates with the tibia at the fibular notch.

Tarsals, Metatarsals and Phalanges

The **tarsus (ankle)** is the proximal region of the foot and consists of seven **tarsal bones.** They include the talus (ankle bone) and **calcaneous** (heel) and are located in the posterior part of the foot. The talus, the uppermost tarsal bone, is the only bone that articulates with the fibula and tibia.

The **metatarsus** is the intermediate region of the foot and consists of the five metatarsal bones numbered I to V from the medial to lateral position. Like the metacarpals of the palm of the hand, each metatarsal consists of proximal base, an intermediate shaft and a distal head. The first metatarsal is thicker than the others because it bears more weight.

The phalanges comprise the distal component of the foot and resemble those of the hand both in number and arrangement. They are numbered I to V beginning with the great toe, which is medial. Each also consists of a proximal base, an intermediate shaft and a distal head.

1.5 STRUCTURE OF BONE

Bones are rigid organs that form part of the endoskeleton of vertebrates. They move, support and protect the various organs of the body, produce red and white blood cells and store minerals. It is a type of connective tissue where the matrix is hard and calcified. The matrix contains many collagen fibers. The term for these layers of the matrix is Lamellae. Since bones come in a variety of shapes and have a complex internal and external structure, they are lightweight, yet strong and hard, in addition to fulfilling their many other functions. One of the types of tissues that make up bone is the mineralized osseous tissue, also called bone tissue that gives it rigidity and honeycomb-like three-dimensional internal structure. Other types of tissue found in bones include marrow, endosteum and periosteum, nerves, blood vessels and cartilage. There are 206 bones in the adult body and about 300 bones in the infant body.

A) Macroscopic Structure of Bone

Bone is a beautiful substance with an intricate structure. To simplify quite a bit, the basic unit is the **Haversian system,** which is a hollow, laminated rod of collagen and calcium phosphate; the hollow core is a nutrient channel, the Haversian canal. Within the shaft of a long bone, many of these Haversian systems are bundled together in parallel, forming a kind of bone called **compact bone,** which is optimized to handle compressive and bending forces. Near the ends of the bones, where the stresses become more complex, the Haversian systems splay out and branch to form a meshwork of **cancellous** or **spongy bone**.

If you cut a cross-section through a region of compact bone, you will see rings of Haversian systems, each with a hole, the canal, in the center. Cutting through the region of cancellous bone produces a more complex section, because the systems have many different orientations.

These have a **diaphysis** or shaft and two **epiphysis** or extremities. The diaphysis is composed of compact bone with a central medullary canal, containing fatty yellow bone marrow. The epiphysis consists of an outer covering of compact bone with spongy (cancellous) bone inside. The **diaphysis** and epiphysis are separated by

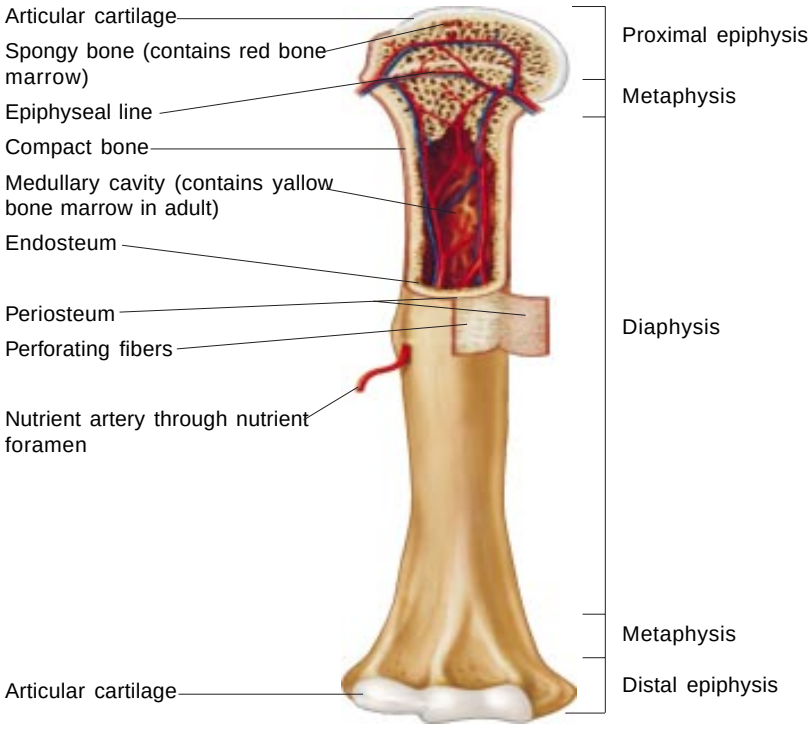


Fig. 1.11: Diagram depicting the general structure of long bones.

epiphyseal cartilages, which ossify when growth is complete. This is made up of **bony bars** (**or trabeculae**) arranged in such a way that they are able to resist any force which is applied upon the bone. Between the bars are many tiny cavities filled with a **red marrow** which contains numerous **red blood corpuscles** in different stages of development. Thickening of a bone occurs by the deposition of new bone tissue under the peritoneum.

Long bones are almost completely covered by a vascular membrane, the **periosteum**, which has two layers. The outer layer is tough and fibrous, and protects the bone underneath. The inner layer contains **osteoblasts** and **osteoclasts,** the cells responsible for bone production and breakdown, and is important in repair and remodeling of the bone. The periosteum covers the whole bone except within joint cavities, allows the attachment of tendons and is continuous with the joint capsule. Hyaline cartilage replaces periosteum on bone surfaces that form joints. Blood supply to the shaft of the bone derives from one or more nutrient arteries; the epiphyses have their own blood supply, although in the mature bone the capillary networks arising from the two are heavily interconnected.

B) Microscopic Structure of Bone

Bone is a strong and durable type of connective tissue. Its major constituents (65%) are a mixture of calcium salts, mainly calcium phosphate. This inorganic matrix provides bone hardness, but on its own it would be brittle and prone to shattering. The third is an organic material called **osteoid**, which is composed mainly of collagen. Collagen is very strong and gives slight flexibility to the bone. The cellular component of bone contributes less than 2% of bone mass. Under the microscope, compact bone shows a definite and a characteristic pattern of arrangement.

Bone Cells

There are three types of cells intimately associated with bone: **osteocytes, osteoblasts,** and **osteoclasts.**

Osteocytes: These cells, possibly, have resorptive capabilities. It is the most numerous type of bone cell and is derived from an osteoblast that is no longer synthesizing collagen. Osteocytes were once considered to be dormant, metabolically inactive cells. There is now evidence that they can synthesize collagen, control bone mineralization within their lacunae, and possibly carry out bone resorption.

Osteoblasts: These arise from marrow stroma cells, and are found on the surfaces where bone is being formed. They may require bone morphogenic proteins for induction into osteoblasts. They are generally regarded as bone forming cells and their most

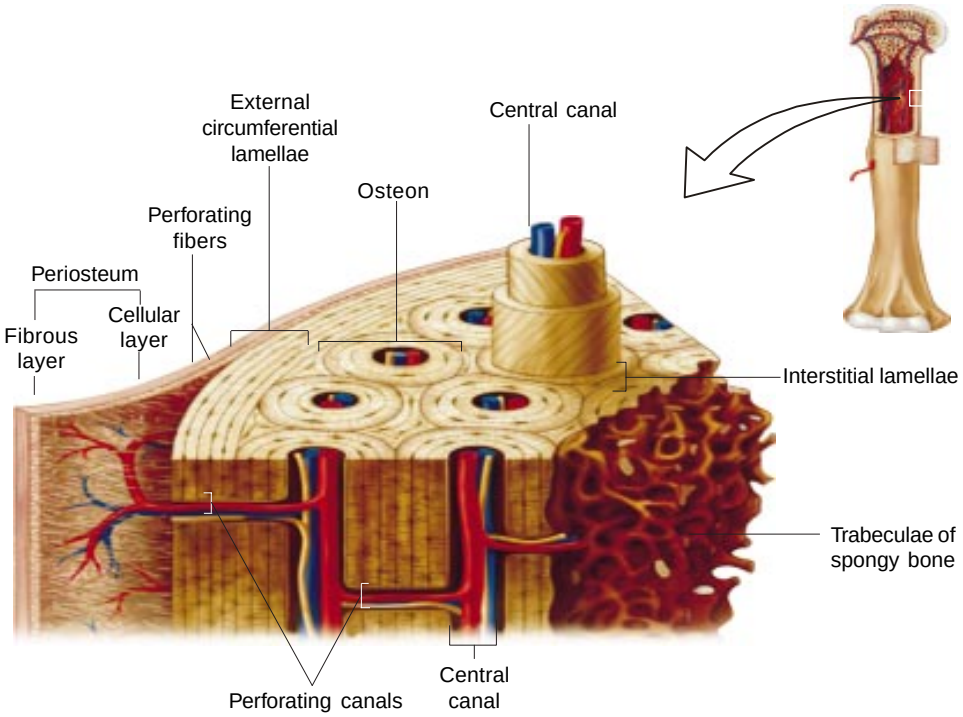


Fig. 1.12: Microscopic structure of bone.

obvious function is to synthesize osteoid. In certain situations, they initiate bone resorption. Osteoblasts synthesize collagen and control its subsequent mineralization. When mature bone is being formed slowly, lining osteoblasts tend to be thin, flat, and elongated. Both cytoplasm and nucleus of osteoblasts contain an enzyme alkaline phosphatase, which can be used as a marker for osteoblast activity.

Osteoclasts: Their function is resorption of bone to maintain the optimum shape. This takes place at bone surfaces, under the periosteum, to maintain the shape of the bones during growth and to remove excess callus formed during healing of fracture. The round walls of the medullary canal during growth and to canalize callus during healing. A fine balance of osteoblast and osteoclast activity maintains normal bone structure and function.

Woven Bone (primary bone): This forms embryonic skeleton, and is largely absent after the age of 4 years. Woven bone formation is seen in fracture callus in both children and adults. Woven bone does not contain lamellae, and rather has a relatively disorganized array of collagen and irregular mineralization pattern.

Lamellar Bone (secondary bone): Layering of bone is the hallmark of mature bone. It is in compact cortical bone of diaphysis that haversian systems are found. Nutrients pass through haversian canals, which run in the direction of the long axis of the bone, to bone cells that lie buried in the thick cortex **osteon**, which refers to the bone surrounding the haversian system. The haversian canals are surrounded by concentric rings or lamellae, each about 5 micrometers thick. **Cement lines** surround the outer border of each osteon.

Canaliculi: Concentric lamellae of mature bones are small lacunae containing osteocytes. Fine canaliculi extend from lacunae that contain cell processes of osteocytes. These processes connect osteocytes to one another and to haversian canal and are the pathways of nutrition from the canal to the bone cells. Since canaliculi are much too small to permit passage of RBC', osteocytes must depend on diffusion and cell pumping mechanisms for their supply of oxygen and nutrients.

1.6 CARTILAGE

Cartilage is a type of dense connective tissue. It is composed of collagen fibers and/or elastin fibers, and can supply smooth surfaces for the movement of articulating bones. Cartilage is found in many places in the body including the joints, the rib cage, the ear, the nose, the bronchial tubes and the intervertebral discs. Cartilage is usually found in close association with bone in the body. It is a type of connective tissue which is tough, semi-transparent, elastic and flexible. The matrix or ground substance of cartilage consists mainly of glycoprotein material, chondroitin. The cartilage cells (chondrocytes) lie scattered in the matrix. Cartilage is covered by a dense fibrous membrane, the perichondrium. No nerves or blood vessels occur in cartilage.

In some vertebrates, such as sharks, the entire skeleton is made up of cartilage. In mammal embryos, the skeleton first forms as cartilage tissue. Cartilage acts as a model and is gradually replaced by bone, as the embryo grows. Such cartilage is known as temporary cartilage. The process by which bone tissue follows the cartilage model and slowly replaces it is known as ossification. Permanent cartilage (cartilage which does not become ossified) is found on the tip of the nose, external ear and walls of trachea (windpipe) and larynx (voice-box).

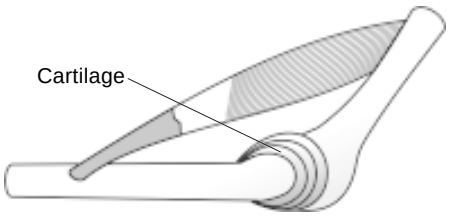


Fig. 1.13: Cartilage.

Structure and Types of Cartilage

There are three main types of cartilage:

(*i*) Elastic Cartilage
(*ii*) Fibrocartilage
(*iii*) Hyaline Cartilage

(*i*) ***Elastic cartilage*** exists in the epiglottis and the eustachian tube. Basically elastic cartilage is similar to hyaline cartilage, but in addition to the collagenous fibres, the matrix of the elastic also contains an abundant network of branched yellow elastic fibres. They run through the matrix in all directions. This type of cartilage is found in the lobe of the ear, the epiglottis and in parts of the larynx.

Functions

Maintain shape

In the ear, for example, elastic cartilage helps to maintain the shape and flexibility of the organ.

Support

Elastic cartilage also strengthens and supports these structures.

(*ii*) ***Fibrocartilage*** often exists temporarily at fracture sites. However, fibrocartilage is permanently present in three major locations in the body like the intervertebral disks of the spine, as a covering of the mandibular condyle in the temporomandibular joint, and in the meniscus of the knee. White fibrocartilage is an *extremely tough tissue*. The orientation of the *bundles* depends upon the stresses acting on the cartilage. The collagenous bundles take up a direction parallel to the cartilage.

Functions

Shock absorbers

The cartilage between the adjacent vertebrae absorbs the shocks that will otherwise damage and jar the bones while we running or walking.

Provides sturdiness without impeding movement.

The white fibrocartilage forms a firm joint between bones but still allows for a reasonable degree of movement.

Deepens sockets

In articular cavities (such as the ball-and-socket joints in the hip and shoulder regions) white fibrocartilage deepens the sockets to make dislocation less possible

(*iii*) *Hyaline cartilage* is most prominently found in diarthroidal joints covering long bones. In addition, hyaline cartilage forms the growth plate by which long bones grow during childhood. Hyaline cartilage is **semi-transparent** and appears **bluish-white in colour.** It is extremely **strong,** but very **flexible** and **elastic.** Hyaline cartilage consists of living cells, **chondrocytes,** which are situated far apart in fluid-filled spaces, the **lacunae.** There is an extensive amount of rubbery **matrix** between the cells and the matrix contains a number of **collagenous fibres.** Hyaline cartilage occurs in **trachea,** the **larynx,** the tip of the nose, in the connection between the **ribs** and the **breastbone** and also the **ends of bone** where they form **joints.** Temporary cartilage in **mammalian embryos** also consists of hyaline cartilage.

Functions

Reduces friction at joints

By virtue of the smooth surface of hyaline cartilage, it provides a sliding area which reduces friction, thus facilitating bone movement.

Movement

Hyaline cartilage joins bones firmly together in such a way that a certain amount of movement is still possible between them.

Support

The c-shaped cartilagenous rings in the windpipes (trachea and bronchi) assist in keeping those tubes open.

Growth

Hyaline cartilage is responsible for the longitudinal growth of bone in the neck regions of the long bones.

Comparison between Cartilage and Bone:

1.7 JOINTS

We have already learnt that the human skeleton consists of more than 200 bones. The individual bones are attached in such a way that a large variety of co-ordinated movements are made possible in different parts of the body. These movements are made possible by **skeletal muscles**, the fact that the bones act as **levers, cartilage**

which reduces fricton and **ligaments** which prevent dislocation and the presence of **movable joints.** The site or place where 2 or more bones of the skeleton are attached to each other is called a joint or place of articulation.

Types of Joints

Joints can be classified according to the degree and type of movement they allow. The following types of joints can be recognized:

***Fibrous (or Immovable) joints*:** These joints are firmly held together by a thin layer of strong connective tissue. There is no movement between the bones such as the sutures of the skull and the teeth in their sockets.

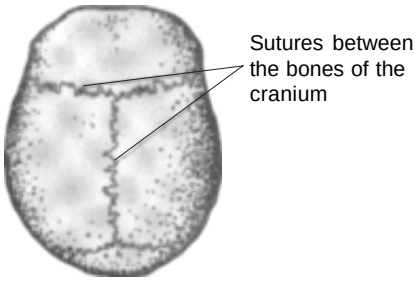


Fig. 1.14: Fibrous joints (Sutures in the skull).

Cartilaginous Joints

Cartilagenous joints are joints where the articular surfaces of the bones forming the joints are attached to each other by means of white fibrocartilaginous discs and ligaments which allow only a limited degree of movement. Examples are the cartilaginous joints between the vertebrae, the cartilage in the symphysis which binds the pubic bones together at the front of the pelvic girdle and the cartilage in the joint between the sacrum and the hip bone.

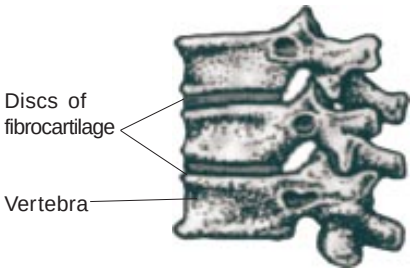


Fig. 1.15: Cartilaginous joints between the thoracic vertebrae.

Synovial Joints

These are freely movable joints. Most of the joints in the body are of the synovial type. The following are the main characteristics of a synovial joint:

The ends of the bones are covered with a layer of smooth hyaline cartilage, called articular cartilage in the joint regions. This reduces friction at the point.

The joint is completely enclosed by a oag-like capsular ligament which holds the joint together and helps to contain the synovial fluid.

The capsular ligament is lined with a synovial membrane. This membrane secretes synovial fluid into the synovial cavity and acts as a seal, waterproofing the joint. The synovial fluid lubricates the joint.

In addition to the capsule, the bones are also attached and held together by strong, tough ligaments made of dense connective tissue. These ligaments prevent dislocation during normal movement.

The articulating surfaces of adjacent bones are reciprocally shaped.

Synovial joints can be subdivided into the following groups according to the type of movement they carry out:

- ### Ball-and-Socket Joints

  These joints are formed where the rounded head of one bone fits into the hollow, cup-shaped socket of another bone such as the shoulder joint and the hip joint. Such joints allow freedom of movement in all directions.

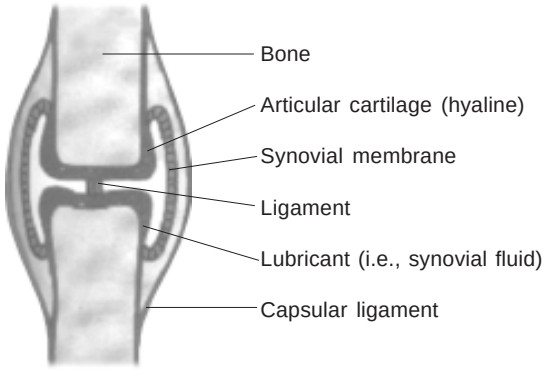


Fig. 1.16: A generalized synovial joint.

- ### Hinge Joints

  These joints occur where the convex surface of one bone fits into the concave surface of another bone, thus making the movement possible in one plane only. Examples of these joints are the knee and the elbow joints. Hinge joints have ligaments mainly at the sides of the joints.

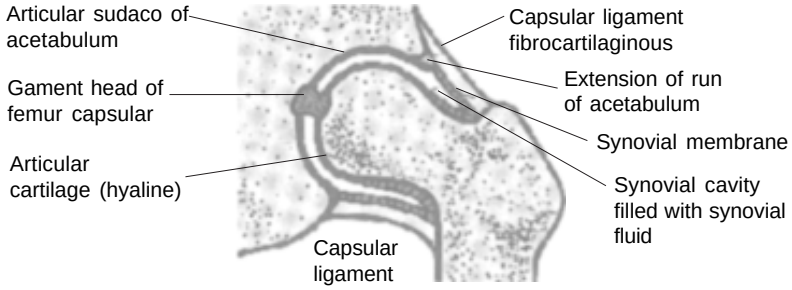


Fig. 1.17: The Hip Joint—ball-and-socket joint.

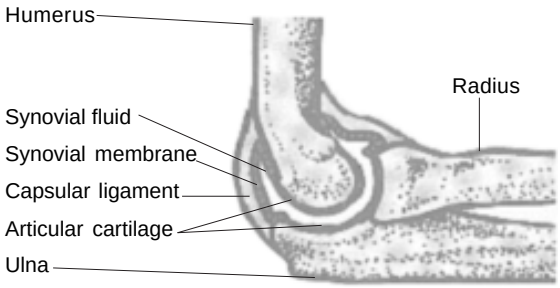


Fig. 1.18. A hinge joint (elbow region).

- ## Gliding Joints

This type of joint allows for gliding movements between flat surfaces as the surfaces slide over one another. Only a limited amount of movement is allowed such as the joints between the carpal bones, the joints between the tarsal bones and those between the articular processes (zygapophyses) of successive vertebrae.

Fig. 1.19: Gliding joints in the wrist region.

- ## Pivot Joints

These joints occur where a bony ring rotates round the pivot (axis) of another bone such as the ring-like atlas rotating around the odontoid process of the axis, allowing the head to turn from side to side. The end of one bone rotates round the axis of another bone, such as the end of the radius rotating around the ulna as the palm of the hand is turned inwards or outwards.

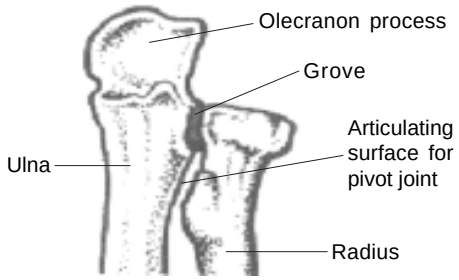


Fig. 1.20: A pivot joint between the radius and ulna.

- ## Compound Joints

  These joints are made up of several joints between a number of different bones. The bones articulate with one another in different ways, allowing for a variety of movements such as the set of joints which operate the movement of the skull on the vertebral column. The condyles at the base of the skull fit into the facets of the atlas, allowing for the nodding movement of the head. While one moves one's head, the atlas is able to rotate round the odontoid process of the axis, allowing the head to turn from side to side. There are also other articulating surfaces, where the atlas and axis meet. All these joints together make a compound joint with its many possible movements in the neck region.

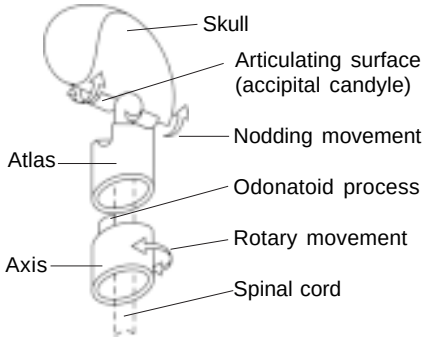


Fig. 1.21: Model showing compound joints in the neck region.

1.8 TENDONS

A tendon (or sinew) is a tough band of fibrous connective tissue that connects muscle to bone and is built to withstand tension. Tendons are similar to ligaments except that ligaments join one bone to another. Tendons and muscles work together and can only exert a pulling force. Tendons play a critical role in the movement of the human body by transmitting the force created by muscles to move bones. In this was, they allow muscles to control movement from a distance. The fingers, for example, are moved

by tendons with force supplied by the forearm muscles. Tendons are constructed primarily of collagenic fibers arranged in a regular formation. This structure provides the strength needed to attach muscles to bones.

Like rope, tendons are tough, fibrous and flexible. These are formed from the same

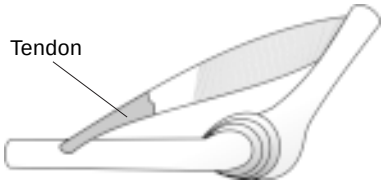


Fig. 1.22: Tendon.

components that make up other kinds of connective tissue, such as cartilage, ligaments and bones. These components are collagen fibers, ground structures, and cells, which in the tendon are called fibrocytes. At the point where a tendon touches bone, the tendon fibers gradually pass into the substance of the bone and meld with it.

Some tendons run inside a fibrous sheath. Between the sheath and the tendon is a thin film of lubricant called synovial fluid. This arrangement helps tendons glide smoothly over surrounding parts.

1.9 LIGAMENTS

Ligaments are fibrous bands or sheets of connective tissue linking two or more bones, cartilages, or structures together and are made of collagen and elastic fibers. The elastic fibers allow the ligaments to stretch to some extent. One or more ligaments provide stability to a joint during rest and movement. Excessive movements such as hyper-extension or hyper-flexion may be restricted by ligaments. Further, some ligaments prevent movement in certain directions. Ligaments surround joints and bind them together. They help strengthen and stabilize joints, permitting movement only in certain directions. Ligaments also connect one bone to another (such as inside the knee).

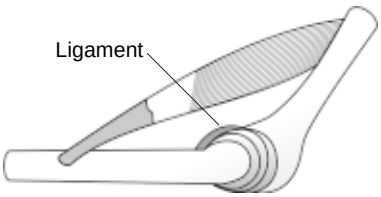


Fig. 1.23: Ligament.

1.10 MUSCULAR SYSTEM

One of the most amazing things about the human body is the incredible range of movement and the mobility it has. This day to day activity is accomplished by our muscles through the extraordinary and fascinating ability of converting chemical energy, energy stored in nutrients into mechanical energy, energy of movement. Muscles are often viewed as the "**machines**" of the body. They help in the movement of food from one organ to another, and carry out our physical movement. The human body contains more than 650 individual muscles that are attached to the skeleton, that provides the pulling power for us to move around. The muscular systems consist of three different types of muscle tissues: **skeletal, cardiac, smooth.** Each of these different tissues has the ability to contract, which then allows body movements and functions. There are two types of muscles in the system: involuntary muscles and voluntary muscles. The muscle which we can control by ourselves are called the voluntary muscles, and the ones we cannot control are the involuntary muscles. The heart, or the cardiac muscle, is an example of involuntary muscle.

Function of Muscular System

The muscular system is composed of specialized cells called muscle fibers. Their functions are as follows:

1. **Contractibility** which is the most predominant. Muscles, where attached to bones or internal organs and blood vessels, are responsible for movement. Nearly all movement in the body is the result of muscle contraction.
2. The integrated action of joints, bones and skeletal muscles produces **obvious movements** such as walking and running.
3. Muscular system also **maintains posture,** joint stability and heat production. Postures such as sitting and standing are maintained as a result of muscle contraction.
4. Skeletal muscles also produce more **subtle movements** that result in various facial expressions, eye movements and respiration.
5. **Heat production** to maintain body temperature is an important by-product of muscle metabolism. Nearly 85% percent of heat produced in the body is the result of muscle contraction.

Types of Muscles

Cardiac muscle

Cardiac muscles are involuntary. These are found only in the heart and make-up the wall of the heart called myocardium. They are controlled by the lower section of the

brain called the medulla oblungata, which controls our involuntary action throughout our body. It would have been horrible if we were to consciously tell our heart to beat, with the consequence of forgetting being death. What about when you went to sleep?

The cardiac muscles is the muscle of the brain. Also, like the skeletal muscles, the cardiac muscle is striated and contracts through the sliding filament method. However it is different from other types of muscles because it forms branching fibers. Unlike the skeletal muscles, the cardiac muscle is attached together instead of being attached to a bone.

Smooth muscle

Smooth muscles are involuntary. The cells are small, and have one nucleus. These are spindle-shaped and do not have striped appearance under the microscope. These form the sheets in the walls of the hollow organs and tubular structure to regulate diameter and propel substances through tracts. They make-up the internal organs, such as **stomach-hyper link, throat-hyper link, small intestine-hyper link,** and all the others, except the heart. And also in the urinary bladder, gallbladder, arteries and veins. Unlike cardiovascular muscles, smooth muscles are generally spherical, as most other human cells are, and each contains one nucleus. The smooth muscles are controlled by the nervous system and hormones. In addition, some local metabolites may also influence contraction. Smooth muscles are often called imvoluntary muscles as we cannot control them consiously.

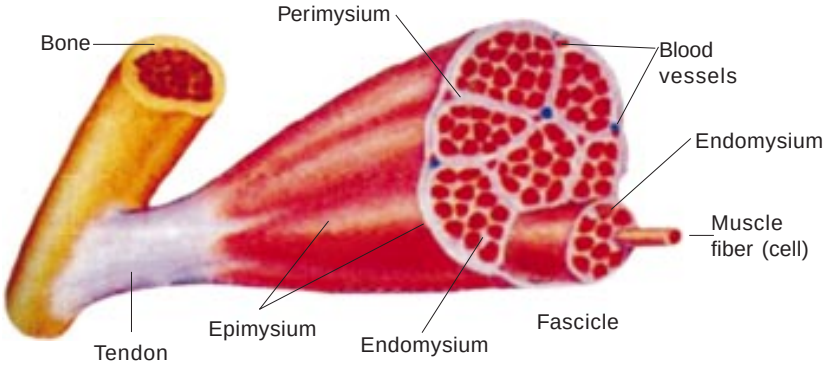
Skeletal muscle

The skeletal muscles are the only voluntary muscles of body system, and make-up the muscular system. They are all the muscles that move the bones and show external movement. Unlike either of the other two classes, skeletal muscles contain multiple nuclei because of its large size, being in strips which are markings are striations make up to a couple of feet long. The skeletal muscle makes up about 40 % of an adults body weight. It is composed of long muscle fibers. Each of these muscles fiber is a cell which contains several nuclei. The nervous system controls the contraction of the muscle. Many of the skeletal muscle contractions are automatic. However, we still can control the action of the skeletal muscle as they are voluntary.

Organisation of skeletal muscle

An individual muscle of the body is made up of muscle tissues, fibrous connective tissues (FCT), and the muscular NAVL. Skeletal muscles are usually attached to bone by tendons composed of connective tissue. This connective tissue also ensheaths the entire muscle and is called **epimysium.** Skeletal muscles consist of numerous subunits

or bundles called **fasicles** (or fascicles). Fascicles are also surrounded by connective tissue (called the **perimysium**) and each fascicle is composed of numerous muscle fibers (or muscle cells). Muscle cells, ensheathed by **endomysium,** consist of many fibrils (or myofibrils), and these myofibrils are made up of long protein molecules called myofilaments. There are two types of **myofilaments** in myofibrils: thick myofilaments and thin myofilaments. Each of the above mentioned connective tissue layers run a length of the muscle. They bind the fibers into a highly organized structure and blend together at each end of the muscle to form the tendon, which connects the muscle to bone. Tendon is like a rope but sometimes takes the form of a broad sheet called aponeurosis.



1.24: Structure of skeletal muscle.

Skeletal muscle fiber

Contraction of a whole skeletal muscle occurs because of coordinated contraction of individual muscle fiber.

Structure

Muscle cells are roughly cylindrical, with diameters between 10 and 100 μm but each fiber may be long up to 35 centimeters long. Each cell is embedded in a basal lamina of collagen and large glycoproteins. Each cell has several nuclei (because the cells are large). Between the fiber and the basal lamina are large numbers of satellite cells that are important in the growth and repair of the fiber. The fiber itself contains specialized structures for excitation-contraction coupling to ensure that a contractile stimulus (received at the synapse) is rapidly and evenly communicated to the whole fiber. Contractile and performance characteristics vary, but are closely linked to the myosin heavy chain isoform expressed by the fiber. Force production occurs in the myofibrils, which are chains of sarcomeres running from one end of the fiber to the other.

Structure of skeletal muscle cell

The cell membrane of a muscle cell is called the sarcolemma, and this membrane, like that of neurons, maintains a membrane potential. So, impulses travel along muscle cell membranes just as they do along nerve cell membranes. However, the 'function' of impulses in muscle cells is to bring about contraction.

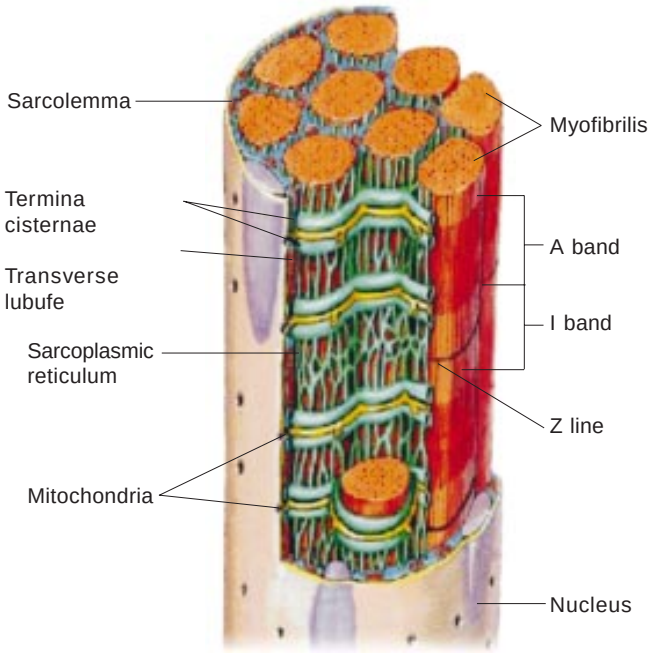


Fig.1.25: Diagram depicting skeletal muscle cell.

The sarcolemma has a unique feature: it has holes in it. These "holes" lead into tubes called transverse tubules (or T-tubules for short). These tubules pass down into the muscle cell and go around the myofibrils. However, these tubules do not open into the interior of the muscle cell; they pass completely through and open somewhere else on the sarcolemma (i.e., these tubules are not used to get things into and out of the muscle cell). The function of T-tubules is to conduct impulses from the surface of the cell (Sarcolemma) down into the cell and, specifically, to another structure in the cell called the sarcoplasmic reticulum.

The **sarcoplasmic reticulum** (SR) is a bit like the endoplasmic reticulum of other cells, e.g., it's hollow. But the primary function of the sarcoplasmic reticulum is to store calcium ions. Sarcoplasmic reticulum is abundant in skeletal muscle cells and is closely associated with the myofibrils (and, therefore, the myofilaments). The membrane of the SR is well-equipped to handle calcium: there are "pumps" (active transport) for

calcium so that calcium is constantly being "pumped" into the SR from the cytoplasm of the muscle cell (called the sarcoplasm). As a result, in a relaxed muscle, there is a very high concentration of calcium in the SR and a very low concentration in the sarcoplasm (and, therefore, among the myofibrils and myofilaments). In addition, the membrane has special openings, or "gates", for calcium. In a relaxed muscle, these gates are closed and calcium cannot pass through the membrane. So, the calcium remains in the SR. However, if an impulse travels along the membrane of the SR, the calcium "gates" open and, therefore, calcium diffuses rapidly out of the SR and into the sarcoplasm where the myofibrils and myofilaments are located. This, as you will see, is a key step in muscle contraction.

Myofibrils are composed of two types of myofilaments: **thick** and **thin**. In skeletal muscle, these myofilaments are arranged in a very regular, precise pattern: thick myofilaments are always surrounded by six thin myofilaments. In a side view, thin myofilaments can be seen above and below each thick myofilament.

Each myofibril is composed of many subunits lined up end-to-end. These subunits are, of course, composed of myofilaments and are called sarcomeres. The drawings show just a very small section of the entire length of a myofibril.

In each sarcomere, thin myofilaments extend in from each end. Thick myofilaments are found in the middle of the sarcomere and do not extend to the ends. Because of this arrangement, when skeletal muscle is viewed with a microscope, the ends of a sarcomere (where only thin myofilaments are found) appear lighter than the central section (which is dark because of the presence of thick myofilaments). Thus, a myofibril has alternating light and dark areas because each consists of many sarcomeres lined up end-to-end. This is why skeletal muscle is called striated muscle (i.e., the alternating light and dark areas look like stripes or striations). The light areas are called the I-Bands and the darker areas the A-Bands. Near the center of each I-Band is a thin dark line called the Z-Line (or Z-membrane in the drawing below). The Z-Line is where adjacent sarcomeres come together and the thin myofilaments of adjacent sarcomeres overlap slightly. Thus, a sarcomere can be defined as the area between Z-lines.

Thick myofilaments are composed of a protein called myosin. Each myosin molecule has a tail, which forms the core of the thick myofilament plus a head that projects out from the core of the filament. These myosin heads are also commonly referred to as cross bridges.

The myosin head has several important characteristics:

It has ATP-binding sites into which the molecules of ATP fit. ATP represents potential energy.

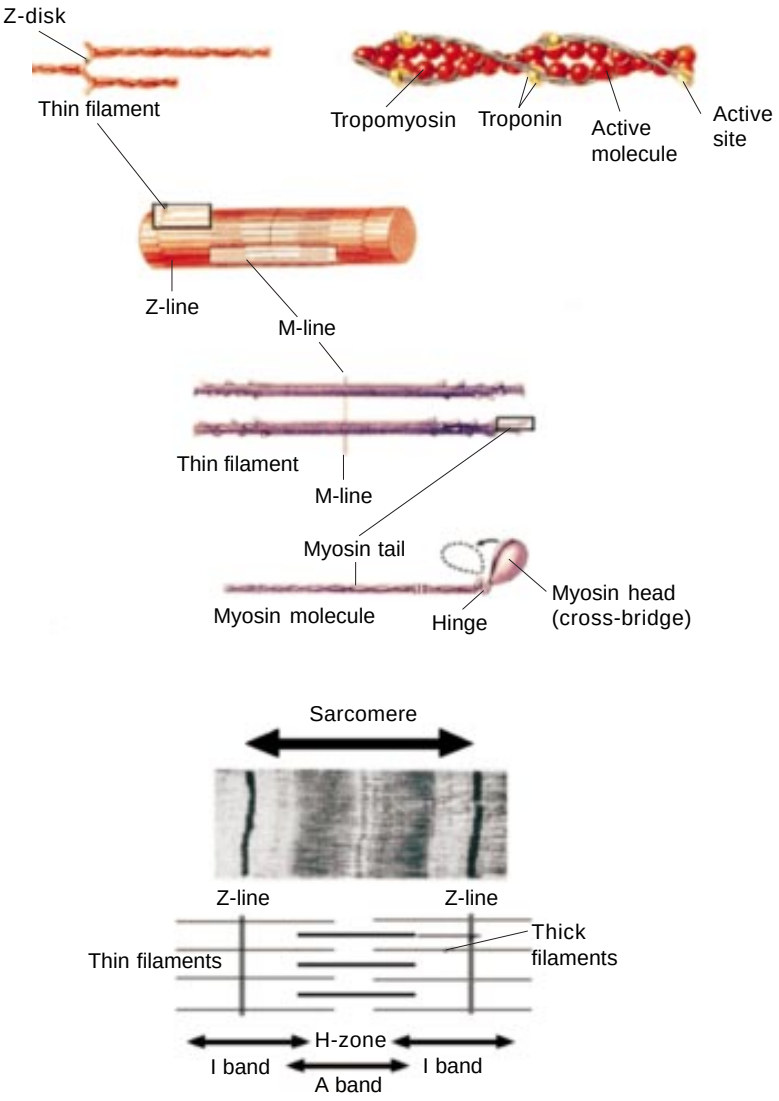


Fig. 1.26: Thick and thin filaments.

It has Actin-binding sites into which molecules of actin fit. Actin is part of the thin myofilament.

It has a "hinge"at the point where it leaves the core of the thick myofilament. This allows the head to swivel back and forth, and the "swivelling" actually causes muscle contraction.

Thin myofilaments are composed of three types of protein: **actin**, **troponin** and **tropomyosin**.

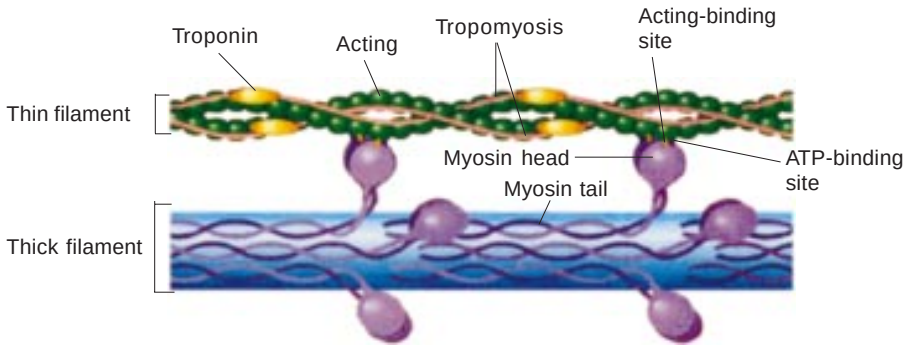
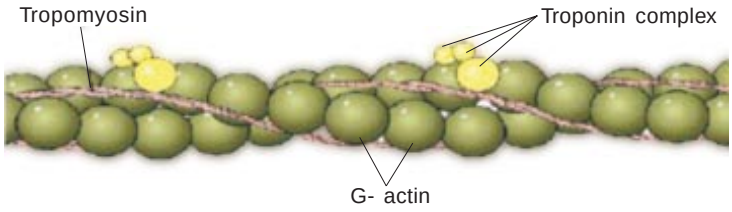


Fig. 1.27: Myosin and the thick filament.



The actin molecules (or G-actin as above) are spherical and form long chains. Each thin myofilament contains two such chains that coil around each other. Tropomyosin molecules are lone, thin molecules that wrap around the chain of actin. At the end of each tropomyosin is a troponin molecule. The tropomyosin and troponin molecules are connected to each other. Each of these three proteins plays a key role in muscle contraction.

Actin: when actin combines with myosin head, the ATP associated with the head breaks down into ADP. This reaction releases energy that causes the myosin head to swivel.

Tropomyosin: In a relaxed muscle, the myosin head of the thick myofilament lies against tropomyosin molecules of the thin myofilament. As long as the myosin heads remain in contact with tropomyosin, nothing happens (i.e., a muscle remains relaxed).

Troponin: Troponin molecules have binding sites for calcium ions. When a calcium ion fills this site, it causes a change in the shape and position of troponin. And, when troponin shifts, it pulls the tropomyosin to which it is attached. When tropomyosin is moved, the myosin head that was touching the tropomyosin now comes in contact with an underlying actin molecule.

Principle of muscle contraction

1. Since skeletal muscle is voluntary muscle, contraction requires a nervous impulse. So, step 1 in contraction is when the impulse is transferred from a neuron to the sarcolemma of a muscle cell.
2. The impulse travels along the sarcolemma and down the T- tubules. From the T-tubules, the impulse passes to the sarcoplasmic reticulum.
3. As the impulse travels along the sarcoplasmic reticulum (SR), the calcium gates in the membrane of the SR open. As a result, calcium diffuses out of the SR and among the myofilaments.
4. Calcium fills the binding site of the troponin molecule. This alters the shape and position of the troponin, which in turn causes movement of the attached tropomyosin molecule.
5. This movement permits the myosin head to contact actin.
6. Contact with actin causes the myosin head to swivel.
7. During the swivel, the myosin head is firmly attached to actin. So, when the head swivels it pulls the actin (and, therefore, the entire thin myofilament) forward. (Obviously, one myosin head cannot pull the entire thin myofilament. Many myosin heads are swivelling simultaneously, or nearly so, and their collective efforts are enough to pull the entire thin myofilament).
8. At the end of the swivel, ATP fits into the binding site on the cross-bridge and this breaks the bond between the cross-bridge (myosin) and actin. The myosin head then swivels back. As it swivels back, the ATP breaks down to ADP and P and the cross-bridge again binds to an actin molecule.
9. As a result, the head is once again bound firmly to actin. However, as the head was not attached to actin when it swiveled back, the head will bind to a different actin molecule (i.e., one further back on the thin myofilament). Once the head is attached to actin, the cross-bridge again swivels. So step 7 is repeated.

As long as calcium is present (attached to troponin), steps 7 through 9 will continue. And, as they do, the thin myofilament is being "pulled" by the myosin heads of the thick myofilament. Thus, the thick and thin myofilaments are actually sliding past each other. As this occurs, the distance between the Z-lines of the sarcomere decreases. As sarcomeres get shorter, the myofibril, of course, gets shorter. And, obviously, the muscle fibers (and entire muscle) get shorter.

Relaxation

Skeletal muscle relaxes when the nervous impulse stops. No impulse means that the membrane of the sarcoplasmic reticulum is no longer permeable to calcium (i.e., no impulse means that the calcium gates are closed). So, calcium no longer diffuses out. The calcium pump in the membrane will now transport the calcium back into the SR. As this occurs, calcium ions leave the binding sites on the troponin molecule. Without calcium, troponin returns to its original shape and position as does the attached tropomyosin. This means that tropomyosin is now back in position, in contact with the myosin head. So, the myosin head is no longer in contact with actin and, therefore, the muscle stops contracting (i.e., relaxes).

So, under most circumstances, calcium is the "switch" that turns muscle "on and off" (contracting and relaxing). When a muscle is used for an extended period, ATP supplies can diminish. As ATP concentration in a muscle declines, the myosin heads remain bound to actin and can no longer swivel. This decline in ATP levels in a muscle causes muscle fatigue. Even though calcium is still present (and a nervous impulse is being transmitted to the muscle), contraction (or at least a strong contraction) is not possible.

Types of contractions

1. **Isotonic**—tension or force generated by the muscle is greater than the load and the muscle shortens.
2. **Isometric**—loads is greater than the tension or force generated by the muscle and the muscle does not shorten.

1.11 THE NEUROMUSCULAR JUNCTION

The axons of motor neurons, carrying impulses to skeletal muscle to produce contraction, divide into the fine filaments terminating in minute pads called motor end plates. At the end point where the nerve reaches the muscle, the myelin sheath is absent and the fine filament passes to a sensitive area on the surface of the muscle fiber. Each muscle fiber is stimulated through a single motor end plate, and one motor nerve has many motor end plates. The motor end plate and sensitive area of the muscle fiber through which it is stimulated is analogous to the synapse between neurons is called the neuromuscular junction. The nerve impulse is passed across the gap between the motor end plate and the muscle fiber by the neurotransmitter, acetylcholine. One nerve fiber and the muscle fibers it supplies constitute a motor unit. Nerve impulses cause serial contraction of motor units in a muscle, and each unit contracts to its full capacity. The strength of contraction depends on the number of motor units in action at a particular time.

Neuromuscular Transmission

The function of neuromuscular junction is to transmit the nerve impulses from nerve to the muscle wherein series of event take place.

1. **Release of Acetylcholine:** When the action potential reaches axon terminal, it increases the permeability of presynaptic membrane for calcium ions by opening the voltage gated calcium channels in the membrane of the axon terminal. Calcium ions enter the axon terminal from extracellular fluid. The calcium ions cause bursting of vesicles so that acetylcholine is released. This is known as exocytosis. The acetylcholine passes through the presynaptic membrane and enters the synaptic cleft.
2. **Action of Acetylcholine:** The acetylcholine molecules bind with nicotinic receptors present in the postsynaptic membrane and form the acetylcholine receptor complex, which opens the ligand gated channels for sodium in the postsynaptic membrane. Now the sodium ions from the extracellular fluid enter the neuromuscular junction through these channels. And there, the sodium ions produce an electrical potential called the endplate potential.
3. **Development of endplate Potential:** The resting membrane potential at the neuromuscular junction is –90 mV. When sodium ions enter inside, slight depolarization occurs up to –60 mV, which is called endplate potential.
4. **Development of miniature endplate potential:** The acetylcholine is released in small quanta from the nerve terminal that produces a weak endplate potential, which is only up to 0.5 mV. It is called miniature potential and it cannot produce action potential in the muscle. When more and more quanta of acetylcholine are released continuously, the miniature end plate potentials are added and finally produce endplate potential resulting in action potential in the muscle.
5. **Fate of Acetylcholine:** Acetylcholine released into the synaptic cleft is destroyed very quickly. Within one millisecond after release into synaptic cleft, it is destroyed by an enzyme, acetylcholinestearase. However, acetylcholine is potent enough that even this short duration is sufficient to excite the muscle fiber.

Muscle fibers

Skeletal muscle fibers are not all the same. They are categorized depending on the varying color.

Red Muscle Fiber: These contain high levels of myoglobin and oxygen storing proteins, which gives them red appearance. These tend to have more mitochondria and blood vessels than the white ones. These have large number of type 1 muscles, also called slow muscles. These have longer contraction time and are sluggish.

Example: Backbone muscles, gastrointestinal muscle etc.

White Muscle Fiber: These have low content of myoglobin and Oxygen and are also called pale muscles. Action has an immediate response.

Skeletal muscle fibers are further classified depending on their twitch capabilities into fast and slow twitch.

Fast Twitch: In these muscle fibers, myosin can split ATP very quickly. These demonstrate a higher capability for electrochemical transmission of action potentials and a rapid level of calcium release and uptake by the sarcoplasmic reticulum. These rely on a well developed, short term, glycolytic system for energy transfer and can contract and develop tension at 2-3 times the rate of slow twitch fibers.

Slow Twitch: These fibers generate energy for ATP re-synthesis by means of a long term system of aerobic energy transfer. They tend to have a low activity level of ATPase, a slower speed of contraction with a less well developed glycolytic capacity. They contain large and numerous mitochondria, and with the high levels of myoglobin that gives them a red pigmentation they have been demonstrated to have high concentration of mitochondrial enzymes, thus they are fatigue resistant.

The two main categories of muscle fibers become three when we split the white muscle fibers into two sections:

Type I: Red fibers which are slow oxidative (also called slow twitch or fatigue resistant fibers).These contain large amounts of myoglobin, many mitochondria, and many blood capillaries.

Red fibers generate ATP by the aerobic system, hence they are also termed “oxidative fibers”. These split ATP at a slow rate, possess slow contraction velocity and are resistant to fatigue. These are found in large number in postural muscles and are needed for aerobic activities like long distance running.

Type IIa: Red fibers which are fast oxidative (also called fast twitch A or fatigue resistant fibers). These contain large amounts of myoglobin, many mitochondria, and many blood capillaries.

These have high capacity for generating ATP by oxidation. These split ATP at a very rapid rate and, hence, have high contraction velocity. These are resistant to fatigue but not as much as slow oxidative fibers. Type IIa are needed for sports such as middle distance running and swimming.

Type IIb: White fibers which are fast glycolytic (also called fast twitch B or fatigable fibers).These contain low myoglobin content, few mitochondria, few blood capillaries

and large amount of glycogen. These split ATP very quickly, but fatigue easily. These fibers are needed for sports like sprinting.

Individual muscles are a mixture of three types of muscle fibers (type 1 and type 2a and b), but their proportions vary depending on the action of that muscle. It must be remembered that skeletal muscles, although a mixture, can have only one type of muscle fiber within a motor unit. For example, if a weak contraction is needed, only type 1 motor units will be activated. These fibers are used mainly for endurance activities. If a stronger contraction is required, the type 2a fibers will be activated or used to assist the type 1 fibers. Maximal contractions facilitate the use of type 2b fibers, which are always activated last. These fibers are used during ballistic activities but tire easily.

It is believed that there are no sex or age differences in fiber distribution. However, relative fiber types vary considerably from muscle to muscle and person to person. Sedentary men and women (as well as young children) have 45% type 2 and 55% type 1 fiber. People at the higher end of any sport tend to demonstrate patterns of fiber distribution e.g., endurance athletes show a higher level of type 1 fibers. Sprint athletes, on the other hand, require large numbers of type 2 b fibers. Middle distance event athletes show approximately equal distribution of the 2 types. This is also often the case in power athletes such as throwers and jumpers.

It has been suggested that various types of exercise can induce changes in the fibers of a skeletal muscle.

It is thought that if you perform endurance type events for a sustained period of time, some of the type 2b fibers transform into type 2a fibers. However, this is argued about. It may well be that the type 2b fibers show enhancements of the oxidative capacity after high intensity endurance training, which brings them to a level at which they are able to perform oxidative metabolism as effectively as slow twitch fibers of untrained subjects. This would be brought about by an increase in mitochondrial size and number and the associated related changes not a change in fiber type.

CHAPTER 2

Nervous System

"Neurons are indeed lotic
Impulse carryover has inborn tactic
Action potential at synapse is just magic
To comprehend entire cognition is too hectic"

2.1 INTRODUCTION

The **nervous system** is a highly specialized network whose principal components are nerves called **neurons**. Neurons are interconnected to each other in complex arrangements, and have the property of conducting, using electrochemical signals, a great variety of stimuli both within the nervous tissue as well as from and towards most of the other tissues. Thus, neurons coordinate multiple functions in organisms. Nervous systems are found in many multicellular animals but differ greatly in complexity between the species.

The *neuron* (nerve cell) is the conducting unit of the nervous system. It is specialized to be irritable and transmit signals, or impulses. The neurons are held together and supported by another nervous tissue known as *neuroglia*, or simply *glia*.

Parts of Nervous System

1. The central nervous system (CNS) consisting of brain and spinal cord.
2. The peripheral nervous system (PNS) consisting of all the nerves outside the brain and the spinal cord. It comprises of paired cranial and sacral nerves. The functional parts are the sensory division and the motor division.

Motor divisions include **voluntary**—the somatic nervous system—and **involuntary**.

3. The autonomic nervous system has two parts – sympathetic and parasympathetic. It has role in functioning of smooth and cardiac muscle and glands.

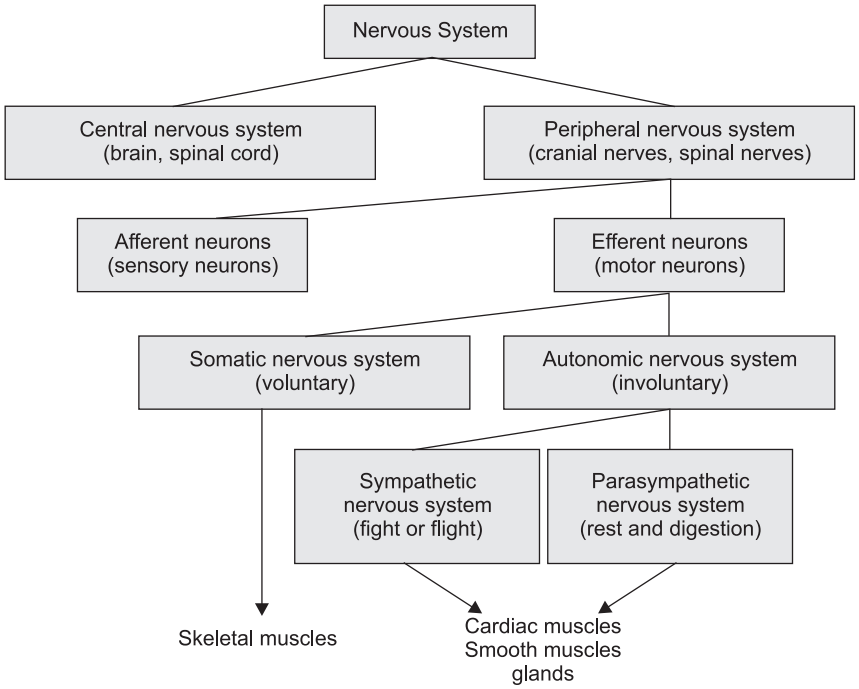


Fig. 2.1: Major subdivisions of the nervous system.

2.2 STRUCTURE OF NEURON

A neuron is the nerve cell body plus all of its processes and coverings. **Neurons** (also known as **neurones** and **nerve cells**) are electrically excitable cells in the nervous system that process and transmit information. In vertebrate animals, neurons are the core components of the brain, spinal cord and peripheral nerves.

Nerve cells are supported by a special type of connective tissue, neuroglia. Each neuron consists of cell body and it possess as one axon and many dendrites. Bundles of axons bound together are called nerves. These cells cannot divide and for survival they need a continuous supply of oxygen and glucose. Unlike other cells, neurons can synthesise chemical energy only from glucose. The physiological units are nerve impulses and action potentials, which are akin to any electrical charges. They are actively involved in the conduction of nerve impulses, and initial strength is maintained throughout the length of the neuron.

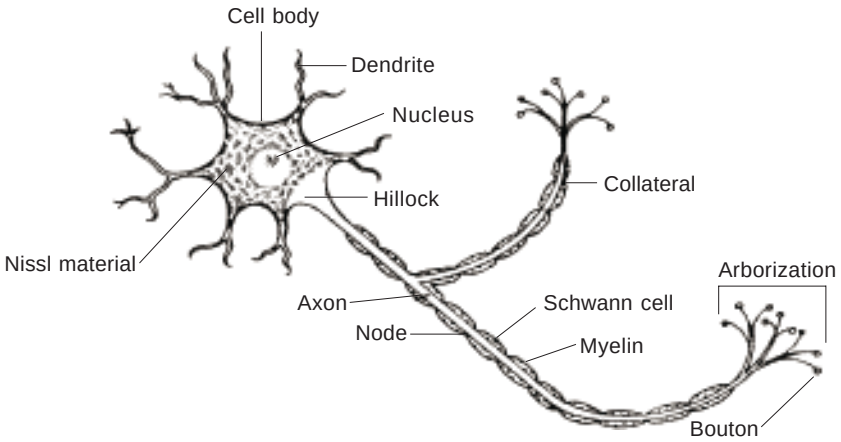


Fig. 2.2: Structure of neuron.

2.3 MORPHOLOGICAL TYPES OF NEURONS

1. **Unipolar Neurons:** The neurons which have only one pole are called the unipolar neurons. From a single pole, both the processes, axon and dendrite arise. This type of nerve cell is present only in embryonic stage in human beings.
2. **Bipolar Neurons:** The neurons with two poles are known as bipolar neurons. Among the two poles, axon arises from one pole and dendrities arise from other pole.
3. **Multipolar Neurons:** These are neurons which have many poles. One of the poles give rise to the axon and all other poles give rise to dendrities.

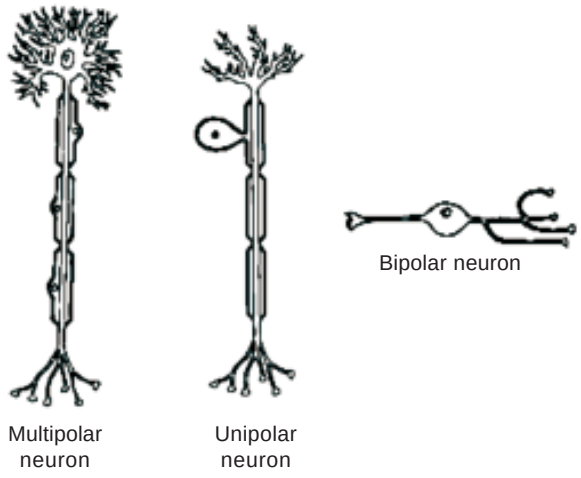


Fig. 2.3: Different types of neurons.

2.4 PHYSIOLOGICAL TYPES OF NEURONS

1. **Sensory Neurons:** These are also called afferent nerve cells. These neurons carry the sensory impulses from periphery to the central nervous system. The sensory neurons have a short axon and long dendrites.
2. **Motor Neurons:** These are also known as efferent nerve cells. These neurons carry the motor impulses from central nervous system to the peripheral effector organs like muscles, glands, blood vessels etc. The motor neurons have long axon and short dendrites.

2.5 NERVOUS TISSUE

The **human nervous system** consists of billions of nerve cells (or neurons) plus supporting (neuroglial) cells. Neurons are able to respond to stimuli (such as touch, sound, light, and so on), conduct impulses, and communicate with each other (and with other types of cells like muscle cells).

Properties of nervous tissue

1. **Irritability:** Ability to transmit the impulses from outside. Monitoring of CO_2 concentration and inturn stimulates for reception of oxygen.
2. **Conductivity:** The action potential is transmitted through the nerve fiber as nerve impulse normally, in the body the action potential is transmitted through the nerve fiber in only one direction. However, experimentally the action potential travels through the nerve fiber in either direction.

Type of Neurons

There are three major classes of neurons: Sensory neurons, internurons and motor neurons.

Sensory neurons

Sensory neurones (*neurons*) are unipolar neuron nerve cells within the nervous system responsible for converting external stimuli from the organism's environment into internal electrical motor reflex loops and several forms of involuntary behavior, including pain avoidance. In humans, such reflex circuits are commonly located in the spinal cord.

In complex organisms, sensory neurons relay their information to the central nervous system or in less complex organisms, such as the hydra, directly to motor neurons. Sensory neurons also transmit information to the brain, where it can be further processed and acted upon. For example, olfactory sensory neurons make synapses with neurons of the olfactory bulb, where the sense of olfaction (smell) is processed.

At the molecular level, sensory receptors located on the cell membrane of sensory neurons are responsible for the conversion of stimuli into electrical impulses. The type of receptor employed by a given sensory neuron determines the type of stimuli it will be sensitive to. For example, neurons containing mechanoreceptors are sensitive to tactile stimuli, while olfactory receptors make a cell sensitive to odors.

These run from the various types of stimulus receptors, e.g., touch, odor, taste, sound and vision. The cell bodies of the sensory neurons leading to the spinal cord are located in clusters, called **ganglia**, next to the spinal cord. The axons usually terminate at interneurons.

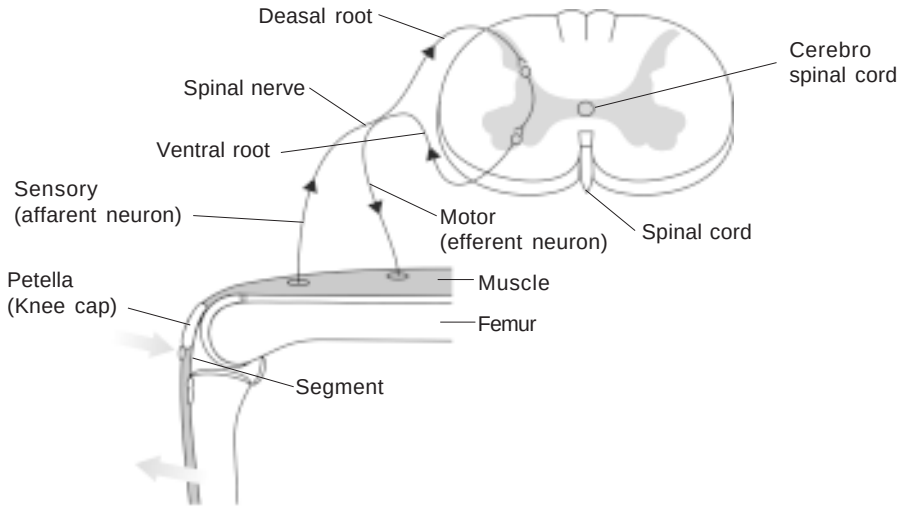


Fig. 2.4: Simplified view of the relationship between sensory and motor nerons running to and from the spinal cord.

Interneurons

These are found exclusively within the spinal cord and brain. They are stimulated by signals reaching them from:

- sensory neurons
- other interneurons or
- both.

Interneurons are also called **association neurons**.

It is estimated that the human brain contains 100 billion (10^{11}) interneurons averaging 1000 synapses on each, i.e., some 10^{14} connections.

The term "interneuron" hides a great diversity of structural and functional types of cells. In fact, it is not yet possible to say how many different kinds of interneurons are present in the human brain. Certainly hundreds; perhaps many more.

Motor neurons

These transmit impulses from the central nervous system to the muscles and glands that carry out the response.

Most motor neurons are stimulated by interneurons, although some are stimulated directly by sensory neurons.

Function

At the interface between a motor neuron and muscle fiber is a specialized synapse called the neuromuscular junction. Upon adequate stimulation, the motor neuron releases a flood of neurotransmitters that bind to postsynaptic receptors and trigger a response in the muscle fiber.

- In invertebrates, depending on the neurotransmitter released and the type of receptor it binds, the response in the muscle fiber could be either excitatory or inhibitory.
- For vertebrates, however, the response of a muscle fiber to a neurotransmitter can only be excitatory, in other words, contractile. Muscle relaxation and inhibition of muscle contraction in vertebrates is obtained only by inhibition of the motor neuron itself. Although muscle innervation may eventually play a role in the maturation of motor activity. This is why muscle relaxants work by acting on the motoneurons that innervate muscles (by decreasing their electrophysiological activity) or on cholinergic neuromuscular junctions, rather than on the muscles themselves.

Somatic motor neurons

Somatic motor neurons are further subdivided into two types: *alpha efferent neurons* and *gamma efferent neurons*. (Both types are called *efferent* to indicate the flow of information from the central nervous system (CNS) to the periphery.)

- *Alpha motor neurons* innervate extrafusal muscle fibers (typically referred to simply as *muscle fibers*) located throughout the muscle. Their cell bodies are in the ventral horn of the spinal cord and they are sometimes called **ventral horn cells**.
- *Gamma motor neurons* innervate intrafusal muscle fibers found within the muscle spindle.

In addition to voluntary skeletal muscle contraction, alpha motor neurons also contribute to muscle tone, the continuous force generated by noncontracting muscle to oppose

stretching. When a muscle is stretched, sensory neurons within the muscle spindle detect the degree of stretch and send a signal to the CNS. The CNS activates alpha motor neurons in the spinal cord, which causes extrafusal muscle fibers to contract and thereby resist further stretching. This process is also called the stretch reflex.

Gamma motor neurons regulate the sensitivity of the spindle to muscle stretching. With the activation of gamma neurons, intrafusal muscle fibers contract so that only a small stretch is required to activate spindle sensory neurons and the stretch reflex.

Functions of nervous tissues

a. Provide sensory awareness through electrochemical input to the central nervous system (CNS) from peripheral receptors. The word "peripheral" refers to parts of the body (e.g., the skin) outside the CNS (which is defined as the brain and the spinal cord).

b. Provide motor responses to sensory input: e.g., reflex muscular movements, voluntary muscular movements and glandular secretions.

c. Analysis of information brought into the CNS or analysis of thoughts generated within the CNS. Analysis in its highest form occurs in the brain and can result in a long delay between a sensory input and a motor response. For example, one may respond to an insult years after the insult was delivered, or we may solve a problem weeks or months after initially becoming aware of the problem.

d. Memory—the ability to recall and integrate previous experiences into the analysis of information.

2.6 CONDUCTION SYSTEM

Stimulus neurons can respond to stimuli and conduct impulses because a membrane potential is established across the cell membrane. In other words, there is an unequal distribution of ions (charged atoms) on the two sides of a nerve cell membrane.

Establishment of the Resting Membrane Potential

Membranes are polarized or, in other words, exhibit a resting membrane potential. This means that there is an unequal distribution of ions (atoms with a positive or negative charge) on the two sides of the nerve cell membrane. This potential generally measures about 70 milli volts (with the inside of the membrane negative with respect to the outside). So, the resting membrane potential is expressed as –70 mV, and the minus means that the inside is negative relative to (or compared to) the outside. It is called resting potential because it occurs when a membrane is not being stimulated or conducting impulses (in other words, it is resting).

Factors Contributing Membrane Potential

Two ions are responsible for contributing membrane potential: sodium (Na+) and potassium (K+). An unequal distribution of these two ions occurs on the two sides of a nerve cell membrane because carriers actively transport these two ions: sodium from the inside to the outside and potassium from the outside to the inside. As a result of this active transport mechanism (commonly referred to as the sodium- potassium pump), there is a higher concentration of sodium on the outside than the inside and a higher concentration of potassium on the inside than the outside.

The nerve cell membrane also contains special passageways for these two ions that are commonly referred to as gates or channels. Thus, there are sodium gates and potassium gates. These gates represent the only way that these ions can pass through the nerve cell membrane. In a resting nerve cell membrane, all the sodium gates are closed and some of the potassium gates are open. As a result, sodium cannot diffuse through the membrane and largely remains outside the membrane. However, some potassium ions are able to diffuse out.

Overall, therefore, there are lots of positively charged potassium ions just inside the membrane and lots of positively charged sodium ions plus some potassium ions on the outside. This means that there are more positive charges on the outside than on the inside. In other words, there is an unequal distribution of ions or a resting membrane potential. This potential will be maintained until the membrane is disturbed or stimulated. Then, if it is a sufficiently strong stimulus, an action potential will occur.

Action Potential

An action potential is a very rapid change in membrane potential that occurs when a nerve cell membrane is stimulated. Specifically, the membrane potential goes from the resting potential (typically –70 mV) to some positive value (typically about +30 mV) in a very short period of time (just a few milliseconds).

What causes this change in potential to occur? The stimulus causes the sodium gates (or channels) to open and, because there is more sodium on the outside than the inside of the membrane, sodium then diffuses rapidly into the nerve cell. All these positively-charged sodiums ions rushing in, causes the membrane potential to become positive (the inside of the membrane is now positive relative to the outside). The sodium channels open only briefly, and then close again.

The potassium channels then open, and, because there is more potassium inside the membrane than outside, positively-charged potassium ions diffuse out. As these positive ions go out, the inside of the membrane once again becomes negative with respect to the outside.

Threshold Stimulus and Potential

- Action potentials occur only when the membrane is stimulated (depolarized) enough so that sodium channels open completely. The minimum stimulus needed to achieve an action potential is called the **threshold stimulus**.
- The threshold stimulus causes the membrane potential to become less negative (because a stimulus, no matter how small, causes a few sodium channels to open and allows some positively-charged sodium ions to diffuse in).
- If the membrane potential reaches the **threshold potential** (generally 5-15 mV less negative than the resting potential), all the voltage-regulated sodium channels open. Sodium ions rapidly diffuse inward, and depolarization occurs.

All-or-None Law: Action potentials occur maximally or not at all. In other words, there is no such thing as a partial or weak action potential. Either the threshold potential is reached and an action potential occurs, or it is not reached and no action potential occurs.

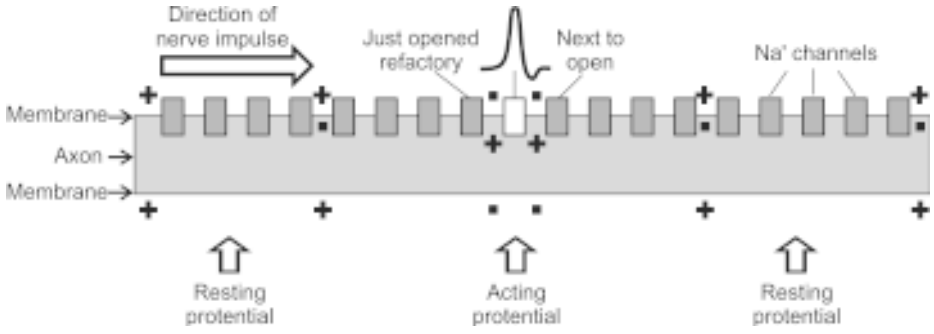


Fig. 2.5: Mode of conduction of nerve impulse.

2.7 CENTRAL NERVOUS SYSTEM (CNS)

The ***central nervous system*** (***CNS***) represents the largest part of the nervous system, including the brain and the spinal cord (Fig.2.6). Together with the peripheral nervous system, it has a fundamental role in the control of behavior. The CNS is contained within the dorsal cavity, with the brain within the cranial cavity, and the spinal cord in the spinal cavity. The CNS is covered by the meninges. The ***brain*** is protected by the skull, and the spinal cord is also protected by the vertebrae.

Major Subdivisions: The fully formed CNS can be considered in two major subdivisions: the **brain** and the **spinal cord**.

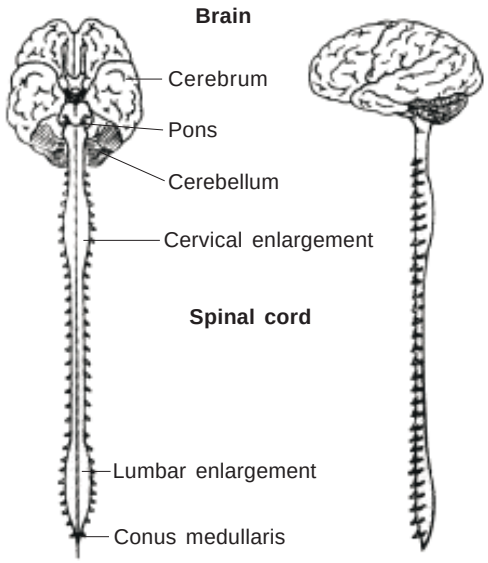


Fig. 2.6: The human central nervous system (CNS).

The Human Brain

The human brain has three major subdivisions: brainstem, cerebellum, and cerebrum.

A. **The Brainstem.** The brainstem is the core of the brain. We consider it in three parts—the hindbrainstem, the midbrainstem, and the forebrainstem. In general, the brainstem is made up of many nuclei and fiber tracts. It is a primary coordinating center of the human nervous system.

BRAINSTEM: It is part of the brain formed by medulla oblongata, pons, and midbrain. It forms:

1. Pathway for ascending and descending tracts of nerve fibers between brain and spinal cord.
2. The location of many important centers for the regulation of vital functions in the body.

MID BRAIN: The midbrain is the area of the brain situated around the cerebral aqueduct between the cerebrum above and the pons below. It consists of nuclei and nerve fibres(tracts), which connect the cerebrum with the lower parts of the brain and the spinal cord. The nuclei act as relay station for ascending and descending nerve fibres.

PONS: They form a bridge between medulla and midbrain. They form a pathway connecting cerebellum with cerebral cortex. The nuclei of 8th, 7th, 6th and 5th cerebral nerves are located in pons. It consists mainly of nerve fibres(white matter) that form the bridge between the two hemispheres of the cerebellum and fibres passing between the higher levels of the brain and spinal cord. Nuclei present within the pons act as relay stations.

MEDULLA OBLONGATA: It is the lower most part of the brain situated below pons and continued downward as spinal cord. It forms the main pathway for ascending and descending tracts of the spinal cord. The outer aspect is composed of white matter, which passes between the brain and the spinal cord. And the gray mater lies centrally. It has **respiratory centers** for maintaining normal rhythmic respiration. From here nerve impulses pass to the phrenic and intercostals nerves which stimulate the contraction of diaphragm and intercostals muscles. **Vasomotor centre** is for control of BP and heart rate. Vomiting center induces vomiting during irritation or inflammation of GI tract. Salivatory nuclei control the secretion of saliva which are maintained by **reflux centres.** Vestibular nuclei contain second order neurons of vestibular nerve. It is about 2.5 cm long and it lies just within the cranium above the foramen magnum. **Cardiovascular centre** controls the rate and force of cardiac contraction and blood pressure.

B. **The Cerebellum.** Over the hindbrainstem is the cerebellum. The cerebellum is connected to both the midbrainstem and the hindbrainstem. The cerebellum is the primary coordinating center for muscle actions. Here, patterns of movements are properly integrated. Thus, information is sent to the appropriate muscles in the appropriate sequences. Also, the cerebellum is very much involved in the postural equilibrium of the body.

C. **The Cerebrum.** Attached to the forebrainstem are the two cerebral hemispheres. Together, these two hemispheres make up the cerebrum. Among related species, the cerebrum is the newest development of the brain.

(1) *Cerebral hemispheres*. The cerebrum consists of two cerebral hemispheres, right and left. They are joined together by a very large fiber tract known as the *corpus callosum* (*the great commissure*).

(2) *Lobes*: Each hemisphere can be divided into four lobes. Each lobe is named after the cranial bone it lies beneath—parietal, frontal, occipital, and temporal. (Actually, there are five lobes. The fifth is hidden at the bottom of the lateral fissure. It is known as the *insula* or *insular lobe.* It is devoted mainly to visceral activities.)

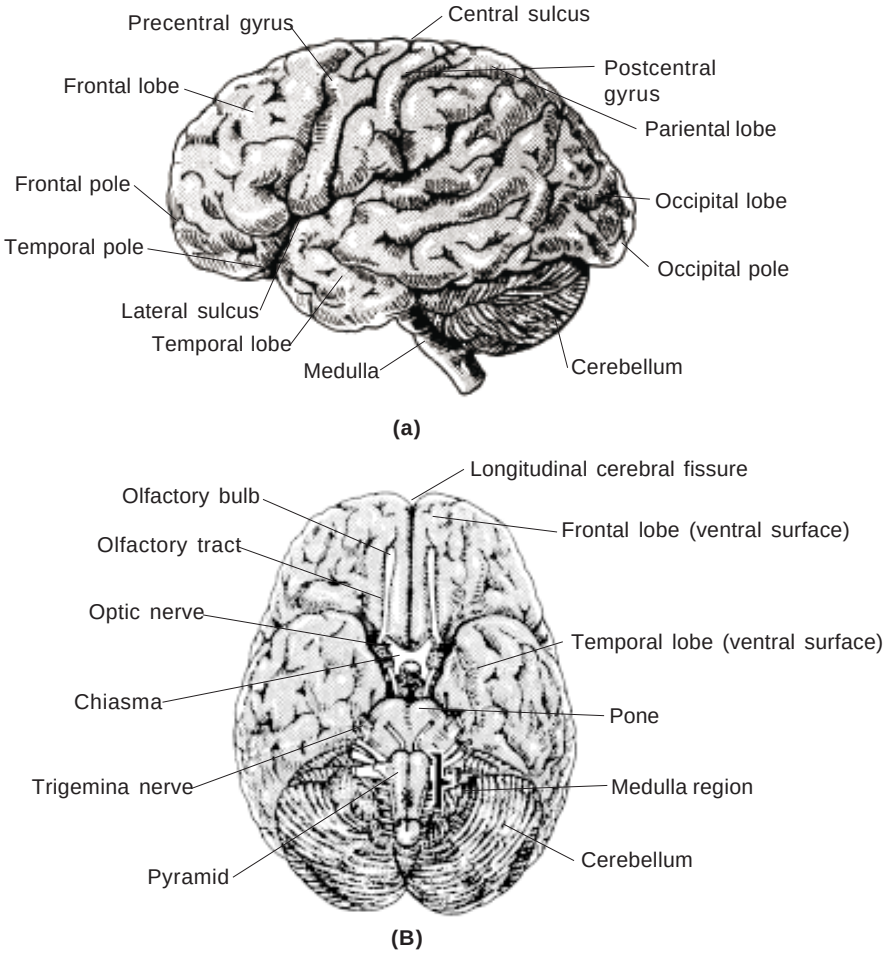


Fig. 2.7: Human brain (a) Side view (b) Bottom view.

(3) *Gyri and sulci.* The *cerebral cortex*, the thin layer at the surface of each hemisphere, is folded. This helps to increase the amount of area available to neurons. Each fold is called a *gyrus*. Each groove between two gyri is called a *sulcus*.

(a) The *lateral sulcus* is a cleft separating the frontal and parietal lobes from the temporal and occipital lobes. Therefore, the lateral sulcus runs along the lateral surface of each hemisphere.

(b) The *central sulcus* is a cleft separating the frontal from the parietal lobe. Roughly, each central sulcus runs from the left or right side of the cerebrum to top center and over into the medial side of the cerebrum.

(c) There are two gyri that run parallel to the central sulcus. Anterior to the central sulcus is the *precentral gyrus*. Posterior to the central sulcus is the *postcentral gyrus.*

The Human Spinal Cord

Extending inferiorly from the brain is the spinal cord (Fig. 2.8).

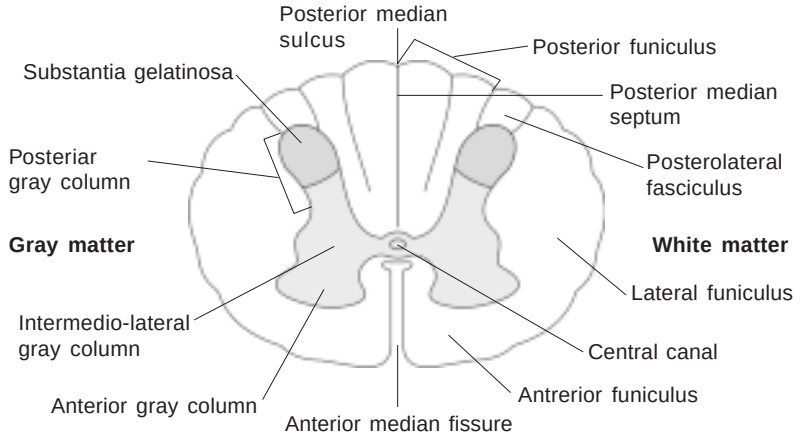


Fig. 2.8: Cross section of spinal cord.

A cross section of the spinal cord

a. The spinal cord is continuous with the brainstem. Together, the spinal cord and the brainstem are called the *neuraxis.* The *foramen magnum* is taken as the point that divides the brainstem from the spinal cord. Thus, the brainstem is within the cranial cavity of the skull, and the spinal cord is within the vertebral (spinal) canal of the vertebral column.

b. The spinal cord has a central portion known as the *gray matter.* The gray matter is surrounded by the *white matter.*

(1) The *gray matter* is made up of the cell bodies of many different kinds of neurons.

(2) The *white matter* is made up of the processes of neurons. The white color is due to their myelin sheaths. These processes serve several purposes: Many make a variety of connections within the spinal cord. Many ascend the neuraxis to carry information to the brain. Many descend the neuraxis to carry commands from the brain.

The spinal cord has two functions:

- ***Transmission of nerve impulses***. Neurons in the white matter of the spinal cord transmit sensory signals from peripheral regions to the brain and motor signals from the brain to peripheral regions.
- ***Spinal reflexes***. Neurons in the gray matter of the spinal cord integrate incoming sensory information and respond with motor impulses that control muscles (skeletal, smooth, or cardiac) or glands.

2.8 PERIPHERAL NERVOUS SYSTEM (PNS)

The **peripheral nervous system (PNS)** has two components: the somatic nervous system and the autonomic nervous system. The PNS consists of all of the nerves that lie outside the brain and spinal cord. **Nerves** are bundles of neuron fibers (axons) that are grouped together to carry information to and from the same structure.

- The **somatic nervous system** is made up of nerves that connect to voluntary skeletal muscles and sensory receptors. It is composed of **afferent** nerves that carry information to the central nervous system (spinal cord) and **efferent** fibers that carry neural impulses away from the central nervous system.
- The **autonomic nervous system** also consists of two components: the sympathetic division and the parasympathetic division. This system mediates much of the physiological arousal (such as rapid heart beat, tremor, or sweat) experienced by a fearful person in an emergency situation.

– The **sympathetic nervous system** mobilizes the body to respond to emergencies.

– The **parasympathetic nervous system** generally helps to conserve the body's energy. It controls normal operations of the body such as digestion, blood pressure, and heart rate. It helps the body return to normal activity after an emergency.

PNS connecting the CNS to all parts of the body are individual organs known as nerves. A *nerve* is a collection of neuron processes together and outside of the CNS. *Peripheral nerves* are nerves which pass from the CNS to the periphery of the body. Together, they are referred to as the *peripheral nervous system*.

a. These nerves are bilateral and segmental.

   (1) *Bilateral*. This means that the peripheral nerves occur in pairs. In each pair, there is one nerve to the right and one to the left.

(2) *Segmental*. The pairs of peripheral nerves occur in intervals, corresponding to the *segments* of the human embryo.

b. Peripheral nerves connected to the brainstem are called *cranial nerves.* They are numbered from I through XII and also have individual names.

c. Peripheral nerves connected to the spinal cord are called *spinal nerves*. They are identified by a letter representing the region of the vertebral column and a number representing the sequence in the region:

(1) Cervical: C-1 through C-8.(2) Thoracic: T-1 through T-12.(3) Lumbar: L-1 through L-5.(4) Sacral: S-1 through S-5.(5) Coccygeal.

Thus, there are 31 pairs of spinal nerves.

Spinal nerves: There are 31 pairs of spinal nerves (62 total). The following discussion traces a spinal nerve as it emerges from the spinal column. A spinal nerve emerges at two points from the spinal cord, the **ventral** and **dorsal** roots.The ventral and dorsal roots merge to form the whole spinal nerve.The spinal nerve emerges from the spinal column through an opening (intervertebral foramen) between adjacent vertebrae. This is true for all spinal nerves except for the first spinal nerve (pair), which emerges between the occipital bone and the atlas (the first vertebra).Outside the vertebral column, the nerve divides into the following branches:

The dorsal ramus contains nerves that serve the dorsal portions of the trunk.The ventral ramus contains nerves that serve the remaining ventral parts of the trunk and the upper and lower limbs.The meningeal branch reenters the vertebral column and serves the meninges and blood vessels within. The rami communicantes contain autonomic nerves that serve visceral functions.Some ventral rami merge with adjacent ventral rami to form a plexus, a network of interconnecting nerves. Nerves emerging from a plexus contain fibers from various spinal nerves, which are now carried together to some target location.

Cranial nerves: These are the nerves of the PNS that originate from or terminate in the brain. There are 12 pairs of cranial nerves, all of which pass through foramina of the skull. Cranial nerves are either sensory nerves (containing only or predominately sensory fibers) or mixed nerves (containing both sensory and motor fibers). Characteristics of the cranial nerves, which are numbered from anterior to posterior as they attach to the brain, are summarized in Table 2.1.

2.9 THE AUTONOMIC NERVOUS SYSTEM

The peripheral nervous system consists of the **somatic nervous system** (SNS) and the **autonomic nervous system** (ANS). The SNS consists of motor neurons that

TABLE. 2.1 Characteristics of cranial nerves.

Cranial Nerve	Nerve Type	Major Functions
I. Olfactory	sensory	smell
II. Optic	sensory	vision
III. Oculomotor	primarily motor	eyeball and eyelid movement; lens shape
IV. Trochlear	primarily motor	eyeball movement; proprioception
V. Trigeminal: ophthalmic branch	sensory	sensations of touch and pain from facial skin, nose, mouth, teeth, and tongue; proprioception motor control of chewing
VI. Trigeminal: maxillary branch	sensory	sensations of touch and pain from facial skin, nose, mouth, teeth, and tongue; proprioception motor control of chewing
VII. Trigeminal: mandibular branch	mixed	sensations of touch & pain from facial skin, nose, mouth, teeth, & tongue; proprioception motor control of chewing
VIII. Abducen	sprimarily motor	eyeball movement; proprioception
IX. Facial	mixed	movement of facial muscles; tear and saliva secretion; sense of taste and proprioception
X. Vestibulo-cochlear: vestibular branch	sensory	hearing
XI. Vestibulo cochlear vestibular branch	sensory	sense of equilibrium
XII. Glossoph-ayrngeal	mixed	sensations of taste, touch and pain from tongue and pharynx; chemoreceptors (that monitor O_2 and CO_2), blood pressure receptors; movement of tongue and swallowing; secretion of saliva
XIII. Vagus	mixed	parasympathetic sensation and motor control of smooth muscles associated with heart, lungs, viscera; secretion of digestive enzymes
XIV. Accessory	primarily motor	head movement; swallowing; proprioception
XV. Hypoglossal	primarily motor	tongue movement, speech and swallowing; proprioception

stimulate skeletal muscles. In contrast, the ANS consists of motor neurons that control smooth muscles, cardiac muscles and glands. In addition, the ANS monitors visceral organs and blood vessels with sensory neurons, which provide input information for the CNS.The ANS is further divided into the **sympathetic nervous system** and the

parasympathetic nervous system. Both of these systems can stimulate and inhibit effectors. However, the two systems work in opposition—one system stimulates an organ, and the other inhibits it. Working in this fashion, each system prepares the body for a different kind of situation, as follows.

- The **sympathetic nervous system** prepares the body for situations requiring alertness or strength or situations that arouse fear, anger, excitement, or embarrassment ("fight-or-flight" situations). In these kinds of situations, the sympathetic nervous system stimulates cardiac muscles to increase the heart rate, causes dilation of the bronchioles of the lungs (increasing oxygen intake), and causes dilation of blood vessels that supply the heart and skeletal muscles (increasing blood supply). The **adrenal medulla** is stimulated to release **epinephrine** (adrenalin) and **norepinephrine** (noradrenalin), which in turn increases the metabolic rate of cells and stimulate the liver to release glucose into the blood. Sweat glands are stimulated to produce sweat. In addition, the sympathetic nervous system reduces the activity of various "tranquil" body functions, such as digestion and kidney functioning.
- The **parasympathetic nervous system** is active during the periods of digestion and rest. It stimulates the production of digestive enzymes and processes of digestion, urination, and defecation. It reduces blood pressure and heart and respiratory rates and conserves energy through relaxation and rest.

In the SNS, a single motor neuron connects the CNS to its target skeletal muscle. In the ANS, the connection between the CNS and its effector consists of two neurons—the **preganglionic neuron** and the **postganglionic neuron**. The synapse between these two neurons lies outside the CNS, in an autonomic ganglion. The axon (preganglionic axon) of a preganglionic neuron enters the ganglion and forms a synapse with the dendrites of the postganglionic neuron emerges from the ganglion and travels to the target organ. There are three kinds of autonomic ganglia:

- The sympathetic trunk, or chain, contains sympathetic ganglia called paravertebral ganglia. There are two trunks, one on either side of the vertebral column along its entire length. Each trunk consists of ganglia connected by fibers, like a string of beads.
- The prevertebral (collateral) ganglia also consist of sympathetic ganglia. Preganglionic sympathetic fibers that pass through the sympathetic trunk (without forming a synapse with a postganglionic neuron) synapse here. Prevertebral ganglia lie near the large abdominal arteries, which the preganglionic fibers target.

- Terminal (intramural) ganglia receive parasympathetic fibers. These ganglia occur near or within the target organ of the respective postganglionic fiber.

A comparison of the sympathetic and parasympathetic pathways is as follows:
Sympathetic Nervous System. Cell bodies of the preganglionic neurons occur in the lateral horns of gray matter of the 12 thoracic and first 2 lumbar segments of the spinal cord. (For this reason, the sympathetic system is also called the **thoracolumbar division**.) Preganglionic fibers leave the spinal cord within spinal nerves through the ventral roots (together with the PNS motor neurons). The preganglionic fibers then branch away from the nerve through white rami (white rami communicantes) that connect with the sympathetic trunk. White rami are white because they contain myelinated fibers. A preganglionic fiber that enters the trunk may synapse in the first ganglion it enters, travel up or down the trunk to synapse with another ganglion, or pass through the trunk and synapse outside the trunk. Postganglionic fibers that originate in ganglia within the sympathetic trunk leave the trunk through gray rami (gray rami communicantes) and return to the spinal nerve, which is followed until it reaches its target organ. Gray rami are gray because they contain unmyelinated fibers.

- **Parasympathetic Nervous System**: Cell bodies of the preganglionic neurons occur in the gray matter of sacral segments S_2-S_4 and in the brain stem (with motor neurons of their associated cranial nerves III, VII, IX, and X). (For this reason, the parasympathetic system is also called the **craniosacral division**, and the fibers arising from this division are called the cranial outflow or the sacral outflow, depending upon their origin.) Preganglionic fibers of the cranial outflow accompany the PNS motor neurons of cranial nerves and have terminal ganglia that lie near the target organ. Preganglionic fibers of the sacral outflow accompany the PNS motor neurons of spinal nerves. These nerves emerge through the ventral roots of the spinal cord and have terminal ganglia that lie near the target organ.

Reflex arc can also be represented by a simple flow diagram (Fig.2.9).

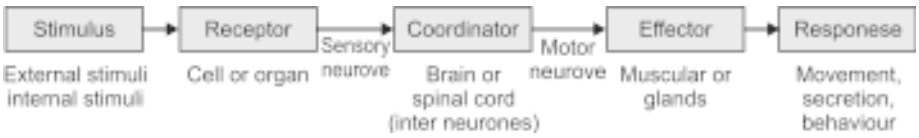


Fig. 2.9: Simple flow diagram of reflex arc.

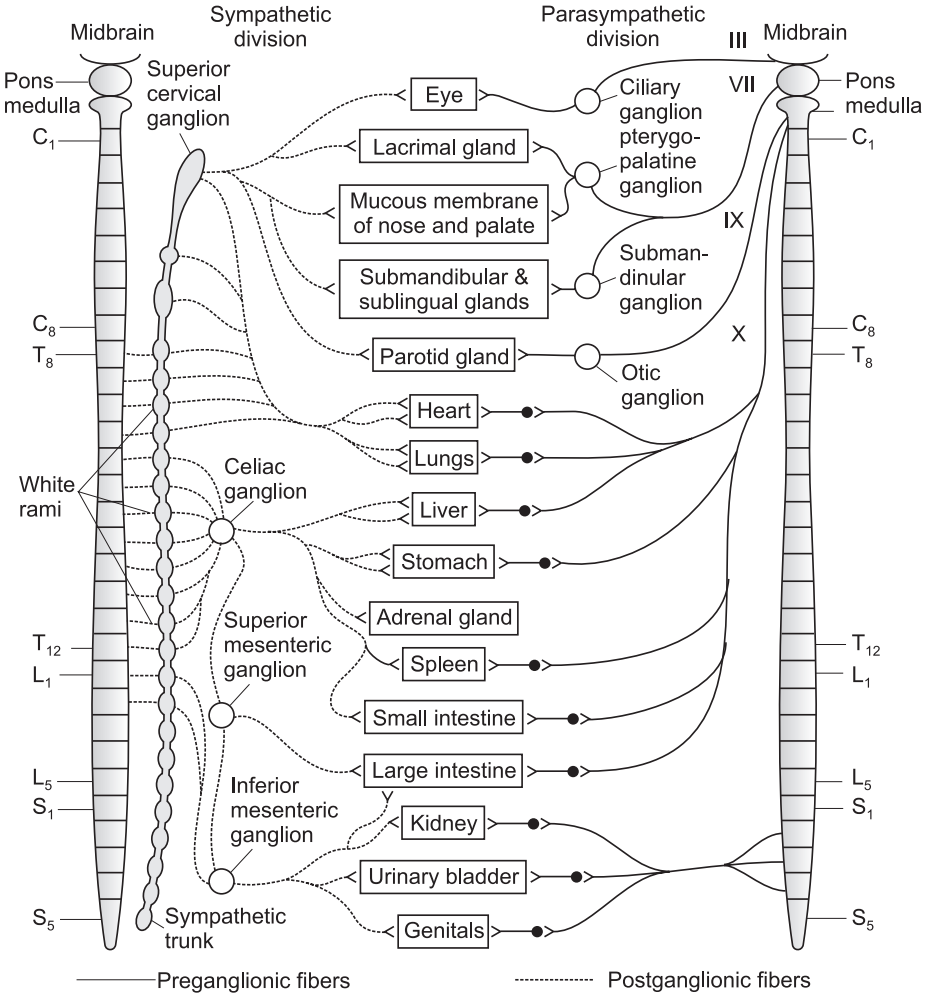


Fig. 2.10: A comparison of the sympathetic and parasympathetic pathways.

2.10 THE GENERAL REFLEX

The simplest reaction of the human nervous system is the reflex. A reflex is defined as an automatic reaction to a stimulus.

The pathway followed by the stimulus (impulse) from beginning to end is the *reflex arc*. The general reflex arc of the human nervous system has a minimum of five components (Fig. 2.11).

a. The stimulus is received by a *receptor organ* specific to that stimulus.

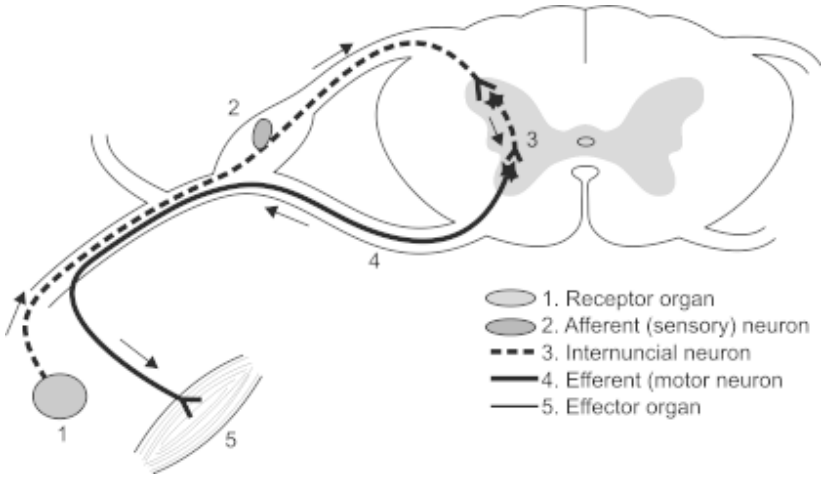


Fig. 2.11: Components of Reflex arc.

b. From the receptor organ, the stimulus is carried to the CNS by way of an *afferent* (sensory) *neuron* within the appropriate peripheral nerve. The cell body of this afferent neuron is located in the posterior root ganglion of a spinal nerve or the individual ganglion of a cranial nerve.

c. Within the spinal cord or brainstem, the terminal of the afferent neuron synapses with the interneuron, or *internuncial neuron.*

INTER = between
NUNCIA = messenger

In turn, the internuncial neuron synapses with the cell body of the efferent (motor) neuron.

d. In the spinal cord, the cell bodies of the *efferent* (motor) *neurons* make up the anterior column of the gray matter. In the brainstem, the motor neurons make up the individual nuclei of the cranial nerves. The axon of the motor neuron passes out of the CNS by way of the appropriate peripheral nerve. Command information is thus carried away from the CNS.

e. The information is then delivered by the motor neuron to the *effector organ. Somatic* motor neurons lead to striated muscle fibers, particularly in skeletal muscles. *Autonomic* (visceral) motor neurons lead to smooth muscle tissue, cardiac muscle tissue, or glands.

2.11 SPECIAL SENSE

There is no firm agreement among neurologists as to the number of senses because of differing definitions of what constitutes a sense. One definition states that an **exteroceptive sense is a faculty by which outside stimuli are perceived**. The conventional **five senses** are sight, hearing, touch, smell, taste: a classification traditionally attributed to Aristotle. However, humans have at least nine different senses (including interoceptive senses), like thermoception (heat, cold), nociception (pain), equilibrioception (balance, gravity), proprioception and kinesthesia (joint motion and acceleration) and sense of time. There are at least two other senses in other organisms (amongst them are electroreception, echolocation, magnetoception, pressure detection, polarized light detection).

A broadly acceptable definition of a sense would be "a system that consists of a group sensory cell types that responds to a specific physical phenomenon, and corresponds to a particular group of regions within the brain where the signals are received and interpreted." Disputes about the number of senses arise typically regarding the classification of the various cell types and their mapping to regions of the brain.

Taste (Tongue)

The sense of taste, or **gustatory sense**, occurs in the taste buds. Located primarily on the tongue, taste buds reside in papillae, the bumps on the tongue that give it a rough texture. The taste bud consists of supporting cells, basal cells, and gustatory (taste) receptor cells arranged in the shape of a glove with an opening, or taste pore, to the outside located at the top. A long microvilli, or gustatory hair, from each gustatory receptor cell within the taste bud projects through the taste pore. Gustatory hairs generate action potentials when stimulated by chemicals that are dissolved in the saliva. Basal cells are actively dividing epithelial cells. The daughter cells of basal cells develop into supporting cells, which subsequently mature into gustatory receptor cells. Since they are easily damaged by the activities that occur in the mouth, gustatory receptor cells are short-lived and replaced about every ten days.

An individual gustatory receptor cell responds to only four taste sensations: sweet, bitter, sour, and salty. All other tastes arise from a mixture of these four tastes in combination with olfactory sensations associated with the substance tasted. Taste buds on certain areas of the tongue seem to specialize for certain tastes. For example, the sensation of sweetness is best detected at the front of the tongue, while bitterness is best detected at the back of the tongue.

Smell

The sense of smell, or **olfactory sense**, occurs in olfactory epithelium that occupies a small area in the roof of the nasal cavity. The olfactory receptor cells are bipolar

neurons whose dendrites have terminal knobs with hairlike cilia protruding beyond the epithelial surface. The cilia, or olfactory hairs, initiate an action potential when they react with a molecule from an inhaled vapor. However, molecules of the vapor must first dissolve in the mucus that covers the cilia before they can be detected. The action potential is transmitted along the axons of the olfactory receptor cells (which form the olfactory nerves) to the olfactory bulbs, where they synapse with sensory neurons of the olfactory tract. Other cells of the olfactory epithelium include columnar supporting cells and basal cells. The basal cells continually divide to produce new **olfactory receptor cells** that, because of their short life, need regular replacement. The replacement of olfactory receptor cells is unusual because most other nerve cells cannot be replaced.

Sight (Eye)

The eye is supported by the following accessory organs:

The eyebrows shade the eyes and help keep away the perspiration that accumulated on the forehead from running into the eyes.

The eyelids (palpebrae) lubricate, protect, and shade the eyeballs. Contraction of the levator palpebrae superioris muscle raises the upper eyelid. Each eyelid is supported internally by a layer of connective tissue, the tarsal plate. Tarsal (Meibomian) glands embedded in the tarsal plate produce secretions that prevent the upper and lower eyelids from sticking together. The inner lining of the eyelid, the conjunctiva, is a mucous membrane, which produces secretions that lubricate the eyeball. The conjunctiva continues beyond the eyelid, folding back to cover the white of the eye.

The eyeball is a hollow sphere whose wall consists of three tunics (layers), shown in Fig. 2.12. The outer fibrous tunic consists of avascular connective tissue. The forward 1/6 portion of this tunic is the cornea, a transparent layer of collagen fibers that forms a window for entering light. The remainder of the fibrous tunic is the sclera. Consisting of tough connective tissue, the sclera maintains the shape of the eyeball and provides for the attachment of the eye muscles. The visible forward portion of the sclera is the white of the eye.

- The **iris** is the colored portion of the eye that opens and closes to control the size of its circular opening, the **pupil**. The size of the pupil regulates the amount of light entering the eye and helps bring objects into focus.
- The ciliary body lies between the iris and the choroids (the remainder of the vascular tunic). The ciliary processes that extend from the ciliary body secrete aqueous humor, the fluid that fills the forward chamber of the eye. The

suspensory ligament between the ciliary processes and the lens hold the lens in place, while ciliary muscles (in the ciliary body) that pull on the suspensory ligament control the shape of the lends to focus images.

- The choroid connects with the ciliary body at a jagged boundary, and forms the remaining portion (5/6) of the vascular tunic. The choroid is dark brown, absorbs light and reduces reflection within the chamber of the eyeball that would otherwise blur images. The highly vascularized choroid provides nutrients to surrounding tissues, including the avascularized fibrous tunic.
- The inner tunic is the **retina.** The retina consists of an outer pigmented epithelium covered by nervous tissue (the neural layer) on the inside. There are two kinds of photoreceptors in the retina:

  Cones are photoreceptor cells that respond to bright light and color. They transmit sharp images. The concentration of cones is low at the sides of the retina.

  Rods are photoreceptor cells that are more sensitive to light and more numerous than cones. As a result, rods provide vision in dim light. They are also more capable of detecting movement. However, rods cannot detect color, and dimly lit objects appear gray. Since the concentration of rods increases in areas farther away from the macula lutea, detecting a moving or dimly lit object can be more effectively achieved by looking slightly away from the object.

Within the nervous tunic, photoreceptor cells (rods and cones) form synapses with other nerve cells. When stimulated by light, rods and cones pass graded potentials to bipolar cells, which, in turn, pass graded potentials to the ganglion cells. The graded potentials may be modified by horizontal cells and amacrine cells that link adjacent photoreceptors or ganglion cells, respectively. Action potentials are ultimately generated by ganglion cells. The axons of all the ganglion cells gather at the optic disc and exit the nervous tunic through the optic disc as the optic nerve. The optic disc is a blind spot because photoreceptors are absent here.

- The lens of the eye consists of tightly packed cells arranged in successive layers (as in an onion) and filled with transparent proteins called crystallins.

When light reflected from an object enters the eye, the following processes occur:

- *Light refraction*. When light rays pass from one substance to another substance of different density, the rays bend, or refract. The amount of bending depends upon the angle of incidence of the light ray and the degree to which the densities of the two substances differ. When distant objects are sighted, the normal curvature of the lens appropriately compensates for the refraction due to the

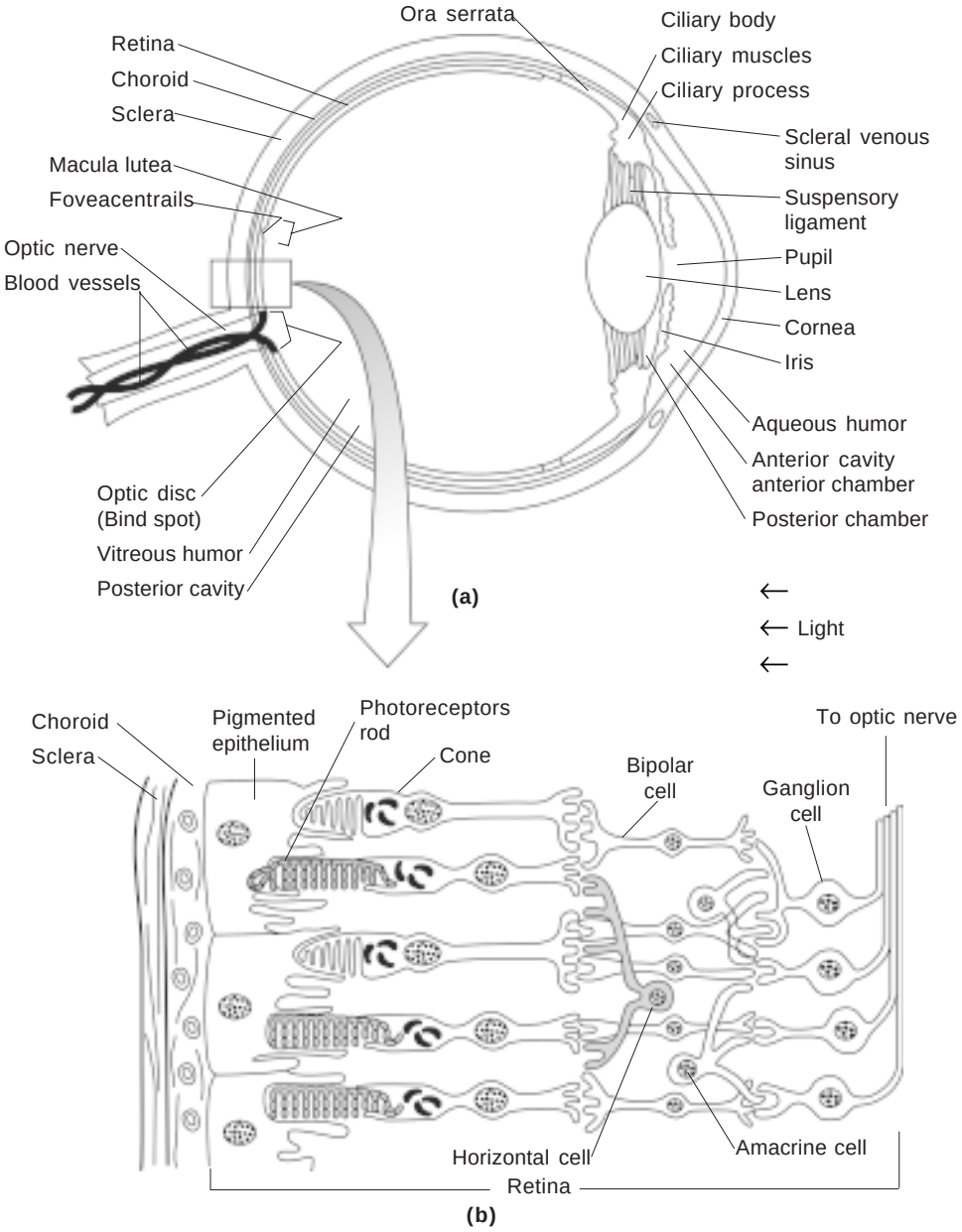


Fig. 2.12: Details of the (a) eye (b) retina.

differences in densities among the aqueous humor, the lens, and the vitreous humor.

- *Lens accommodation*. Light rays from near objects enter the eyeball at more divergent angles than rays from distant objects. Thus, when near objects are

sighted, muscles pull on the lens to increase its curvature so that the more divergent rays of the close object are properly refracted upon the retina.

- *Pupil constriction*. One function of the pupil is to regulate the amount of light that enters the posterior cavity so that the retina receives the appropriate amount of stimulation. In addition, when near objects are sighted, the pupil constricts (accommodation papillary reflex) to block the most divergent light rays that cannot be brought into focus by the accommodation of the lens. Reading under low levels of light may be difficult because the pupils are dilated to allow all available light to enter rather than constricted to improve focusing. Increasing the amount of light improves the ability to read because the surplus light permits the pupils to constrict and the lens to focus a more narrow beam of light rays.
- *Eyeball convergence*. Both eyes point in the same direction when viewing a distant object. When near objects are sighted, the eyes must be directed medially to simultaneously view the object, a process called convergence.

Nerve impulses generated by visual stimuli travel along the axons of ganglion cells within the two optic nerves. Before entering the brain, axons representing the medial portions of the visual fields of each eye cross over at the optic chiasma. After the crossover, the axons, now forming the optic tract, enter the thalamus. Processed visual stimuli are then carried to visual areas of the occipital lobes of both cerebral hemispheres by nerve pathways called the optic radiations.

Touch or somatic senses: The somatic (general) senses collect information about cutaneous sensations (tactile sensations on the surface of the skin) and proprioceptive sensations. The following stimuli are detected:

Tactile stimuli are detected by mechanoreceptors and produce sensations of touch and pressure.

Root hair plexuses are receptors with free nerve endings that surround hair follicles and detect hair movement.

Corpuscles of touch (Meissner's corpuscles) are receptors with encapsulated nerve endings located in the dermal paillae (near the surface) of the skin that detect surface pressure (light touch).

Thermal stimuli are detected by free nerve ending thermoreceptors sensitive to heat or cold. Pain stimuli are detected by free nerve ending nociceptors.

Hearing

Sound is produced by Vibrations in Matter (Air, Liquids, Solids): Anything which causes matter to vibrate will produce sound. Vocal cords vibrate and push on the air flowing through the larynx, causing the air to vibrate.

Pitch is Determined by the Frequency of Vibration: We perceive fast vibrations as high pitches and slow vibrations as low pitches. When we are young we can hear vibrations from about 20 hertz to about 20,000 hertz.

Sound Intensities Are Measured in Decibels: The stronger the vibration (the higher the sound pressure) the louder the noise. The scale used for sound intensity is logarithmic because of the very wide range of sound intensities that we encounter. The ear is sensitive to sound. Intensities over a range of a million to one sound intensities are given in decibels (dB). The human ear can respond to a range of sound intensities of about a million to one. For an instance the number of decibels is:

- Decibels = 20 X log (1,000,000/1) = 120
- Sounds louder than this will be painful and will damage the ear

- A few examples of sound intensities:
  - Threshold of hearing (4000 herz) = 0 dB
  - Soft whisper = 20 dB
  - Conversation = 60 dB
  - Busy traffic = 70 dB
  - Rock band = 120 dB
  - Pain threshold = 130 dB

Basic Ear Anatomy

The Ear Has 3 Essential Parts (Fig. 2.13)

- mechanism for collecting and amplifying sound

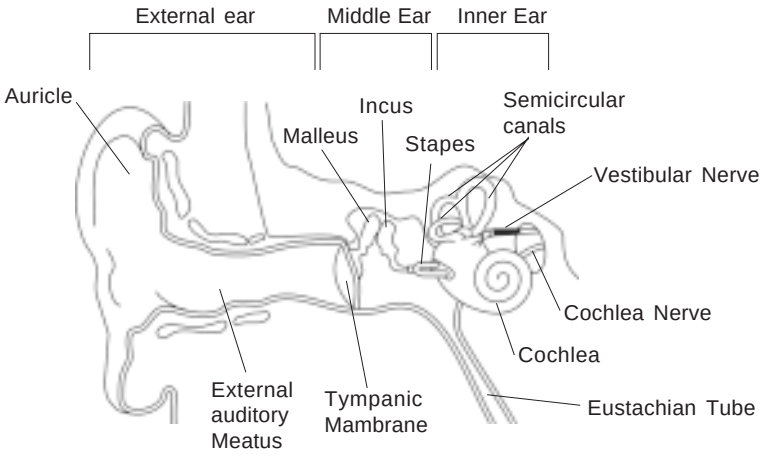


Fig. 2.13: Structure of ear.

- a transducer to convert sound vibrations into action potentials
- nerves to deliver the action potential signals to the brain for interpretation

The Outer Ear Collects Sound Waves

- The pinna (auricle) and ear canal funnel the waves inward to the eardrum (tympanic membrane)
- The waves cause the eardrum to vibrate

Bones of the Middle Ear (Malleus, Incus, Stapes) Amplify the Sound Waves

- The eardrum attaches to the malleus (hammer)
- The malleus attaches to the incus (anvil), which in turn attaches to the stapes (stirrup)
- The stapes is attached to the oval window of the cochlea
- Because of the way the bones are attached together, the vibrations in the oval window are 20X larger than those in the eardrum (amplification)
- If the sound is too loud, small muscles attached to the ear bones contract and dampen the vibrations.

The Cochlea Converts Sound Vibrations to Action Potentials in the Auditory Nerve

- Vibration of the oval window causes cochlear fluid (perilymph & endolymph) to vibrate
- The fluid vibrations in turn cause the basilar membrane to vibrate, producing traveling waves
- The basilar membrane vibrations cause hair cells to bend generate potential
- If generator potentials are large enough, they will stimulate fibers of the auditory nerve to produce action potentials
- Different pitches are detected in different parts of the cochlea:
  - High pitches produce traveling waves at the base of the cochlea (near the oval window)
  - Low pitches produce traveling waves at the apex.

Balance

Equilibrium is maintained in response to two kinds of motion:

- Static equilibrium maintains the position of the head in response to linear movements of the body, such as starting to walk or stopping.
- Dynamic equilibrium maintains the position of the head in response to rotational motion of the body, such as rocking (as in a boat) or turning.

The perception of equilibrium occurs in the vestibular apparatus, which consists of the vestibule and the semicircular canals. Motion in these two structures is detected as follows:

- The vestibule is the primary detector of changes in static equilibrium. A sensory receptor called a macula is located in the walls of the saccule and utricle, the two bulblike sacs of the vestibule. A macula contains numerous receptor cells called hair cells, from which numerous stereocilia (long microvilli) and a single kinocilium (a true cilium) extend into a glycoprotein gel, the otolithic membrane. Calcium carbonate crystals called otoliths pervade the otolithic membrane, increasing its density and thus responsiveness to changes in motion. Changes in linear motion cause the otolithic membrane to move forward and backward in the utricle or up and down in the saccule. The movement of the otolithic membrane causes similar movements in the embedded stereocilia of the hair cells, which in turn initiate graded potentials.
- The semicircular canals are the primary detector of changes in dynamic equilibrium. The three canals, individually called the anterior, posterior, and lateral canals, are arranged at right angles to one another. The expanded base of each canal, called an ampulla, contains a sensory receptor, or crista ampullaris. Like the maculae of the vestibule, each crista contains numerous hair cells whose stereocilia and kinocilium protrude into a gelatinous matrix, the cupula (which is analogous to the otolithic membranes of the maculae). Changes in rotational motion cause the cupula and the embedded stereocilia to move, which stimulates the hair cell to generate a graded potential.

Graded potentials in the hair cells of the maculae and cristae result in changes in the amounts of neurotransmitter secreted. In response to these changes, action potentials are generated in the fibers of the vestibular nerve, which subsequently joins the vestibulocochlear nerve. From here, the nerve impulses travel to the pons and the cerebellum.

CHAPTER 3

Respiratory System

"Respiration is a vital process
Cater to adequate gaseous access
Inhalation is through the noses
Exhalation ensue with metabolic success"

3.1 INTRODUCTION

Respiratory System, in anatomy and physiology, includes organs that deliver oxygen to the circulatory system for transport to all body cells. Oxygen is essential for cells, which use this vital substance to liberate the energy needed for cellular activities. In addition to supplying oxygen, the respiratory system aids in the removed of carbon dioxide, thus preventing the lethal buildup of this waste product in body tissues. Day-in and day-out, without the prompt of conscious thought, the respiratory system carries out its life-sustaining activities. If the respiratory system's tasks are interrupted for more than a few minutes, serious, irreversible damage to tissues occurs, followed by the failure of all body systems, and ultimately, death.

Respiration is the sequence of events that results in the exchange of oxygen and carbon dioxide between the atmosphere and the body cells. Every 3 to 5 seconds, nerve impulses stimulate the breathing process, or ventilation, which moves air through a series of passages into and out of the lungs. After this, there is an exchange of gases between the lungs and the blood. This is called external respiration. The blood transports the gases to and from the tissue cells. The exchange of gases between the blood and tissue cells is internal respiration. Finally, the cells utilize the oxygen for their specific activities. This is cellular metabolism, or cellular respiration. Together these activities constitute respiration.

While the intake of oxygen and removal of carbon dioxide are the primary functions of the respiratory system, it plays other important roles in the body. The respiratory system helps regulate the balance of acid and base in tissues, a process crucial for the normal functioning of cells. It protects the body against disease-causing organisms and toxic substances inhaled with air. The respiratory system also houses the cells that detect smell, and assists in the production of sounds for speech.

The respiratory and circulatory systems work together to deliver oxygen to cells and remove carbon dioxide in a two-phase process called respiration. The first phase of respiration begins with breathing in, or inhalation. Inhalation brings air from outside the body into the lungs. Oxygen in the air moves from the lungs through blood vessels to the heart, which pumps the oxygen-rich blood to all parts of the body. Oxygen then moves from the bloodstream into cells, which completes the first phase of respiration. In the cells, oxygen is used in a separate energy-producing process called cellular respiration, which produces carbon dioxide as a byproduct. The second phase of respiration begins with the movement of carbon dioxide from the cells to the bloodstream. The bloodstream carries carbon dioxide to the heart, which pumps the carbon dioxide-laden blood to the lungs. In the lungs, breathing out, or exhalation, removes carbon dioxide from the body, thus completing the respiration cycle.

3.2 STRUCTURE OF THE RESPIRATORY SYSTEM

The respiratory system is represented by the following structures (Fig. 3.1).

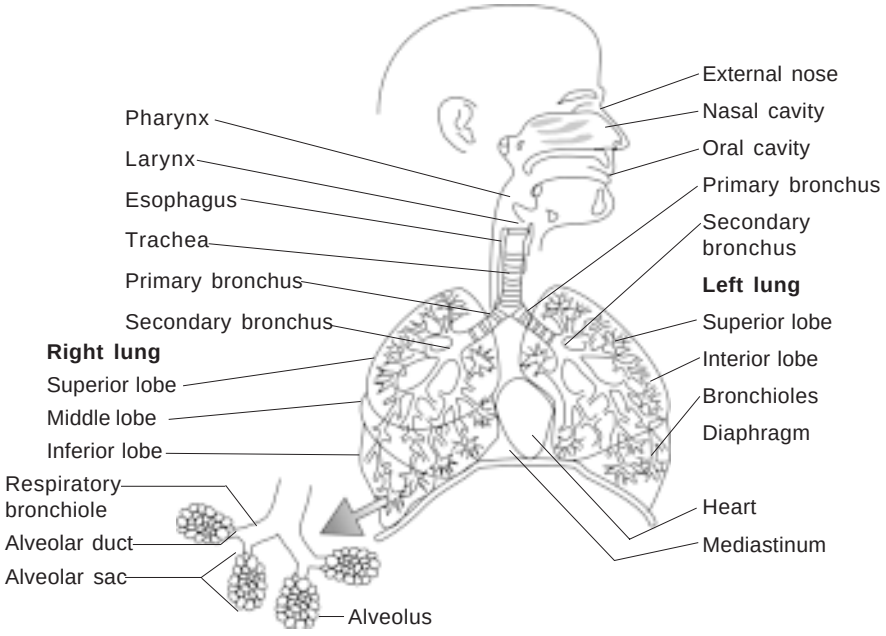


Fig. 3.1: The respiratory system

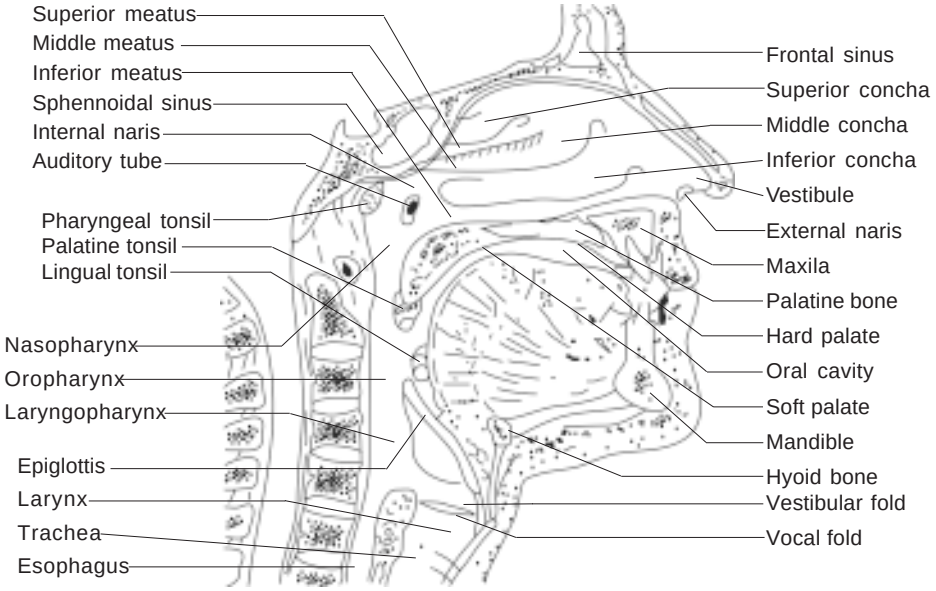


Fig. 3.2 Anterior and sagittal section of the larynx and the trachea.

The **nose** consists of the visible external nose and the internal nasal cavity. The nasal septum divides the nasal cavity into right and left sides. Air enters two openings, the external nares (nostrils; singular, naris), and passes into the vestibule and through passages called meatuses. The bony walls of the meatuses, called concha, are formed by facial bones (the inferior nasal concha and the ethmoid bone). From the meatuses, air then funnels into two (left and right) internal nares. Hair, mucus, blood capillaries, and cilia that line the nasal cavity filter, moisten, warm, and eliminate debris from the passing air.

The pharynx (throat) consists of the following three regions, listed in order through which incoming air passes:

The **nasopharynx** receives the incoming air from the two internal nares. The two auditory (Eustachian) tubes that equalize air pressure in the middle ear also enter here. The pharyngeal tonsil (adenoid) lies at the back of the nasopharynx.

The **oropharynx** receives air from the nasopharynx and food from the oral cavity. The palatine and lingual tonsils are located here.

The **laryngopharynx** passes food to the esophagus and air to the larynx.

The larynx receives air from the laryngopharynx. It consists of the following nine pieces of cartilage that are joined by membranes and ligaments, shown in Fig. 3.3.

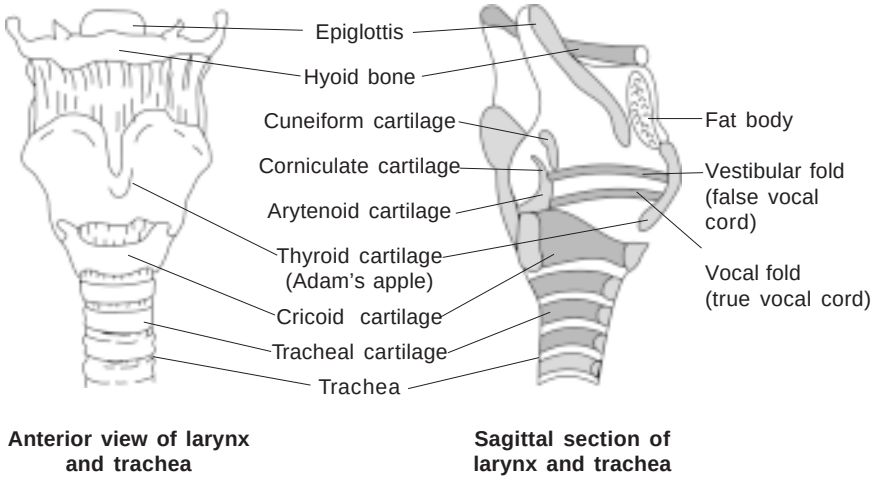


Fig. 3.3 A view of the entire respiratory system and the upper respiratory tract.

The epiglottis, the first piece of cartilage of the larynx, is a flexible flap that covers the glottis, the upper region of the larynx, during swallowing to prevent the entrance of food.

The thyroid cartilage protects the front of the larynx. A forward projection of this cartilage appears as the Adam's apple.

The paired arytenoids cartilages in the rear are horizontally attached to the thyroid cartilage in the front by folds of mucous membranes. The upper vestibular folds (false vocal cords) contain muscle fibers that bring the folds together and allow the breath to be held during periods of muscular pressure on the thoracic cavity (straining while defecating or lifting a heavy object, for example). The lower vocal folds (true vocal cords) contain elastic ligaments that vibrate when skeletal muscles move them into the path of outgoing air. Various sounds, including speech, are produced in this manner.

The cricoid cartilage, the paired cuneiform cartilages, and the paired corniculate cartilages are the remaining cartilages supporting the larynx.

The trachea (windpipe) is a flexible tube, 10 to 12 cm (4 inches) long and 2.5 cm (1 inch) in diameter, whose wall consists of four layers.

The mucosa is the inner layer of the trachea. It contains mucusproducing goblet cells and pseudostratified ciliated epithelium. The movement of the cilia sweeps debris away from the lungs toward the pharynx.

The submucosa is a layer of areolar connective tissue that surrounds the mucosa.

Hyaline cartilage forms 16 to 20 C-shaped rings that wrap around the submucosa. The rigid rings prevent the trachea from collapsing during inspiration.

The adventitia is the outermost layer of the trachea. It consists of areolar connective tissue.

The primary bronchi are two tubes that branch from the trachea to the left and right lungs.

Inside the lungs, each primary bronchus divides repeatedly into branches of smaller diameters, forming secondary (lobar) bronchi, tertiary (segmental) bronchi, and numerous orders of bronchioles (1 mm or less in diameter), including terminal bronchioles (0.5 mm in diameter) and microscopic respiratory bronchioles. The wall of the primary bronchi are constructed like the trachea, but as the branches of the tree get smaller, the cartilaginous rings and the mucosa are replaced by smooth muscle.

Alveolar ducts are the final branches of the bronchial tree. Each alveolar duct has enlarged, bubble-like swellings along its length. Each swelling is called an alveolus, and a cluster of adjoining alveolar is called an alveolar sac. Some adjacent alveoli are connected by alveolar pores.

The respiratory membrane consists of the alveolar and capillary walls. Gas exchange occurs across this membrane. Characteristics of this membrane are as follows:

Type I cells are thin, squamous epithelial cells that constitute the primary cell type of the alveolar wall. Oxygen diffusion occurs across these cells.

Type II cells are cuboidal epithelial cells that are interspersed among the type I cells. Type II cells secrete pulmonary surfactant (a phospholipid bound to a protein) that reduces the surface tension of the moisture that covers the alveolar walls. A reduction in surface tension permits oxygen to diffuse more easily into the moisture. A lower surface tension also prevents the moisture on opposite walls of an alveolus or alveolar duct from cohering and causing the minute airway to collapse.

Alveolar macrophage (dust cells) wander among the other cells of the alveolar wall removing debris and microorganisms.

A thin epithelial basement membrane forms the outer layer of the alveolar wall.

A dense network of capillaries surrounds each alveolus. The capillary walls consist of endothelial cells surrounded by a thin basement membrane. The basement membranes of the alveolus.

The organs of the respiratory system extend from the nose to the lungs and are divided into the upper and lower respiratory tracts. The upper respiratory tract consists of the nose and the pharynx, or throat. The lower respiratory tract includes the larynx,

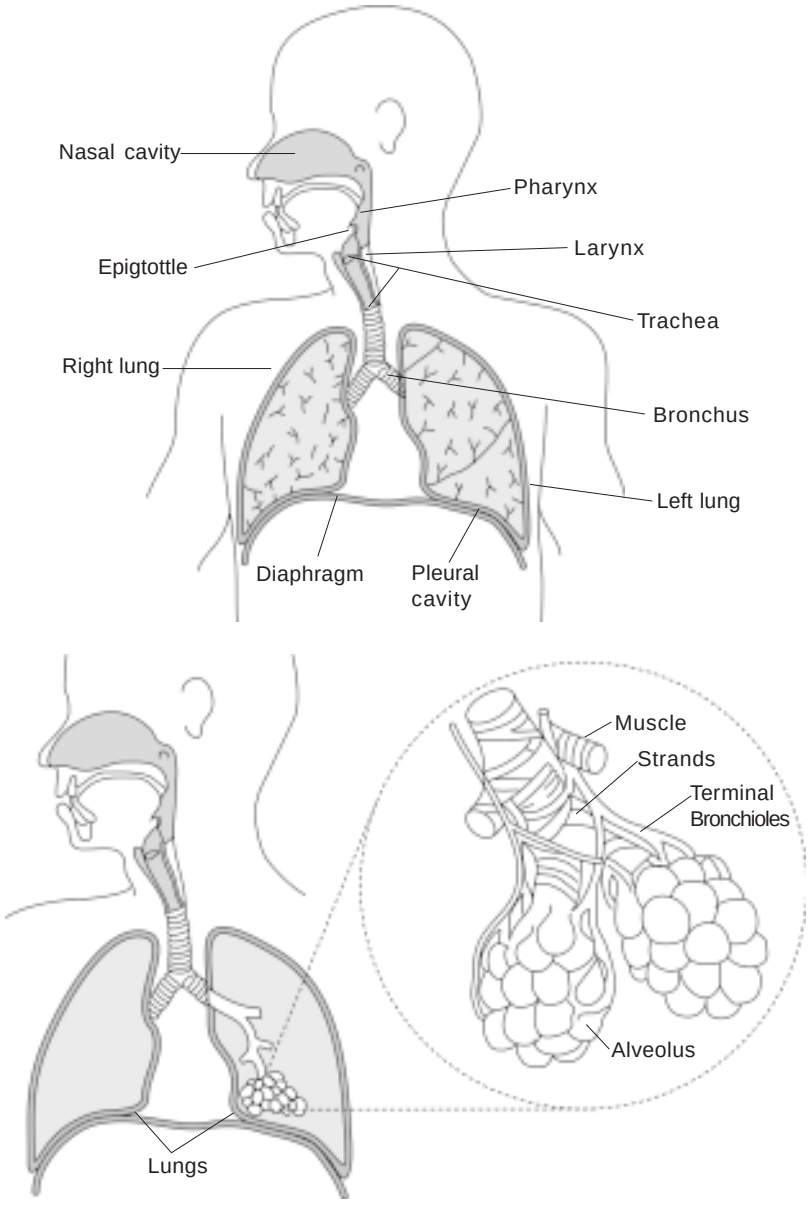


Fig. 3.4:

or voice box; the trachea, or windpipe, which splits into two main branches called bronchi; tiny branches of the bronchi called bronchioles; and the lungs, a pair of sac-like, spongy organs. The nose, pharynx, larynx, trachea, bronchi, and bronchioles conduct air to and from the lungs. The lungs interact with the circulatory system to deliver oxygen and remove carbon dioxide.

3.3 NASAL PASSAGES

The flow of air from outside of the body to the lungs begins with the nose, which is divided into the left and right nasal passages. The nasal passages are lined with a membrane composed primarily of one layer of flat, closely packed cells called epithelial cells. Each epithelial cell is densely fringed with thousands of microscopic cilia, fingerlike extensions of the cells. Interspersed among the epithelial cells are goblet cells, specialized cells that produce mucus, a sticky, thick, moist fluid that coats the epithelial cells and the cilia. Numerous tiny blood vessels called capillaries lie just under the mucous membrane, near the surface of the nasal passages. While transporting air to the pharynx, the nasal passages play two critical roles: they filter the air to remove potentially disease-causing particles; and they moisten and warm the air to protect the structures in the respiratory system.

Filtering prevents air-borne bacteria, viruses, other potentially disease-causing substances from entering the lungs, where they may cause infection. Filtering also eliminates smog and dust particles, which may clog the narrow air passages in the smallest bronchioles. Coarse hairs found just inside the nostrils of the nose trap air-borne particles as they are inhaled. The particles drop down onto the mucous membrane lining the nasal passages. The cilia embedded in the mucous membrane wave constantly, creating a current of mucus that propels the particles out of the nose or downward to the pharynx. In the pharynx, the mucus is swallowed and passed to the stomach, where the particles are destroyed by stomach acid. If more particles are in the nasal passages than the cilia can handle, the particles build up on the mucus and irritate the membrane beneath it. This irritation triggers a reflex that produces a sneeze to get rid of the polluted air.

The nasal passages also moisten and warm air to prevent it from damaging the delicate membranes of the lung. The mucous membranes of the nasal passages release water vapor, which moistens the air as it passes over the membranes. As air moves over the extensive capillaries in the nasal passages, it is warmed by the blood in the capillaries. If the nose is blocked or “stuffy” due to a cold or allergies, a person is forced to breathe through the mouth. This can be potentially harmful to the respiratory system membranes, since the mouth does not filter, warm, or moisten air.

In addition to their role in the respiratory system, the nasal passages house cells called olfactory receptors, which are involved in the sense of smell. When chemicals enter the nasal passages, they contact the olfactory receptors. This triggers the receptors to send a signal to the brain, which creates the perception of smell.

3.4 PHARYNX

Air leaves the nasal passages and flows to the pharynx, a short, funnel-shaped tube about 13 cm (5 in) long that transports air to the larynx. Like the nasal passages, the

pharynx is lined with a protective mucous membrane and ciliated cells that remove impurities from the air. In addition to serving as an air passage, the pharynx houses the tonsils, lymphatic tissues that contain white blood cells. The white blood cells attack any disease-causing organisms that escape the hairs, cilia, and mucus of the nasal passages and pharynx. The tonsils are strategically located to prevent these organisms from moving further into the body. One tonsil, called the adenoids, is found high in the rear wall of the pharynx. A pair of tonsils, the palatine tonsils, is located at the back of the pharynx on either side of the tongue. Another pair, the lingual tonsils, is found deep in the pharynx at the base of the tongue. In their battles with disease-causing organisms, the tonsils sometimes become swollen with infection. When the adenoids are swollen, they block the flow of air from the nasal passages to the pharynx, and a person must breathe through the mouth.

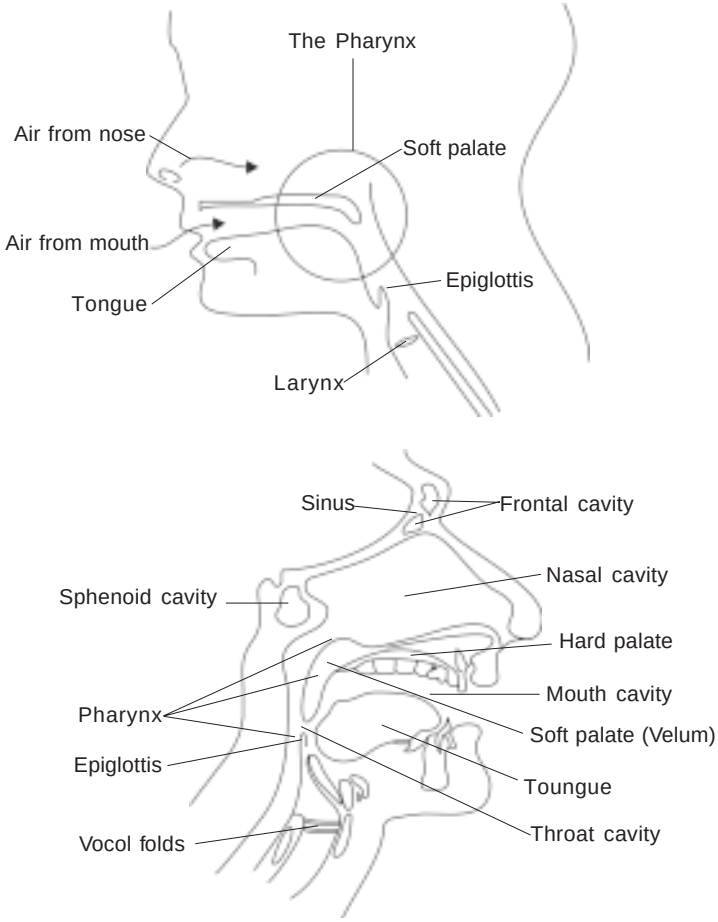


Fig. 3.5: Pharynx.

3.5 BRONCHUS

A **bronchus** (plural **bronchi**, adjective **bronchial**) is a caliber of airway in the respiratory tract that conducts air into the lungs. No gas exchange takes place in this part of the lungs.

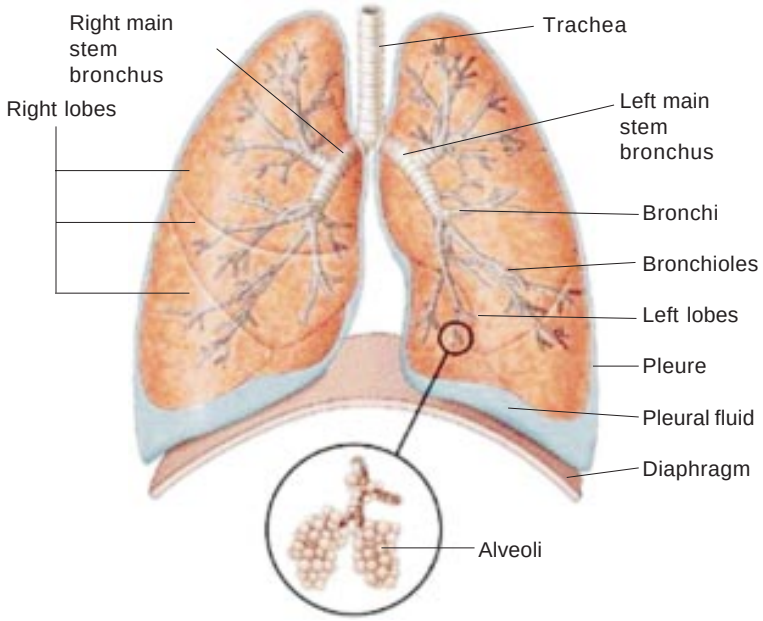


Fig. 3.6: Diagrammatic view of bronchi.

A) Anatomy

The trachea (windpipe) divides into two main bronchi (also **mainstem bronchi**), the left and the right, at the level of the sternal angle. The right main bronchus is wider, shorter, and more vertical than the left main bronchus. The right main bronchus subdivides into three segmental bronchi, while the left main bronchus divides into two. The lobar bronchi divide into tertiary bronchi. Each of the segmental bronchi supplies a bronchopulmonary segment. A bronchopulmonary segment is a division of a lung that is separated from the rest of the lung by a connective tissue septum. This property allows a bronchopulmonary segment to be surgically removed without affecting other segments. There are ten segments per lung, but due to anatomic development, several segmental bronchi in the left lung fuse, giving rise to eight. The segmental bronchi divide into many primary bronchioles, which further divide into terminal bronchioles, each of which then gives rise to several respiratory bronchioles that go on to divide into 2 to 11 alveolar ducts. There are 5 or 6 alveolar sacs associated with each alveolar duct. The alveolus is the basic anatomical unit of gas exchange in the lung.

There is hyaline cartilage present in the bronchi, present as irregular rings in the larger bronchi (and not as regular as in the trachea), and as small plates and islands in the smaller bronchi. Smooth muscle is present continuously around the bronchi.

In the mediastinum, at the level of the fifth thoracic vertebra, the trachea divides into the right and left primary bronchi. The bronchi branch into smaller and smaller passageways until they terminate in tiny air sacs called alveoli.

The cartilage and mucous membrane of the primary bronchi are similar to that in the trachea. As the branching continues through the bronchial tree, the amount of hyaline cartilage in the walls decreases until it is absent in the smallest bronchioles. As the cartilage decreases, the amount of smooth muscle increases. The mucous membrane also undergoes a transition from ciliated pseudostratified columnar epithelium to simple cuboidal epithelium to simple squamous epithelium.

The alveolar ducts and alveoli consist primarily of simple squamous epithelium, which permits rapid diffusion of oxygen and carbon dioxide. Exchange of gases between the air in the lungs and the blood in the capillaries occurs across the walls of the alveolar ducts and alveoli.

B) Role in Disease

Bronchitis is defined as an inflammation of the bronchi. There are two main types: acute and chronic. Acute bronchitis is usually caused by viral or bacterial infections. Chronic bronchitis is a form of COPD, (chronic obstructive pulmonary disease) usually associated with smoking or long-term exposure to irritants. Asthma is hyperreactivity of the bronchi with an inflammatory component, often in response to allergens.

While the left mainstem bronchus departs from the trachea at an angle, the right mainstem bronchus is almost a vertical continuation of the trachea. This anatomy predisposes the right lung to several problems:

If food, liquids, or foreign bodies are aspirated, they will often lodge in the right mainstem bronchus. This may result in aspiration pneumonia.

If the endotracheal tube used for intubation is inserted too far, it usually lodges in the right mainstem bronchus. This allows ventilation of the right lung, but leaves the left lung useless.

Patients with inadequate cough reflexes may develop chronic right middle lobe lung infections such as the Lady Windermere Syndrome.

3.6 LARYNX

the **larynx** (plural *larynges*), colloquially known as the **voicebox**, is an organ in the neck of mammals involved in protection of the trachea and sound production. The

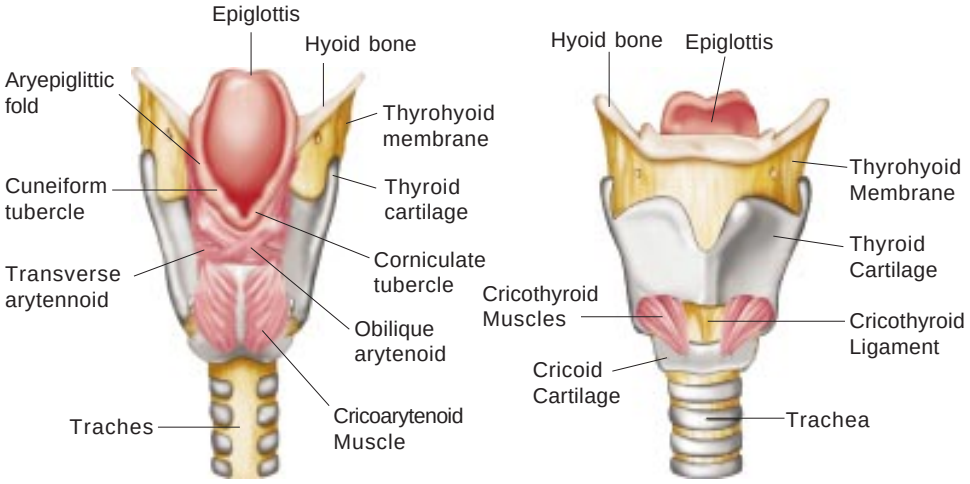


Fig. 3.7:

larynx houses the vocal folds, and is situated just below where the tract of the pharynx splits into the trachea and the esophagus.

Function

Sound is generated in the larynx, and that is where pitch and volume are manipulated. The strength of expiration from the lungs also contributes to loudness, and is necessary for the vocal folds to produce speech.

Fine manipulation of the larynx is used in a great way to generate a source sound with a particular fundamental frequency, or pitch. This source sound is altered as it travels through the vocal tract, configured differently based on the position of the tongue, lips, mouth, and pharynx. The process of altering a source sound as it passes through the filter of the vocal tract creates many different vowel and consonant sounds of the world's languages.

During swallowing, the backward motion of the tongue forces the epiglottis over the laryngeal opening to prevent swallowed material from entering the lungs; the larynx is also pulled upwards to assist this process. Stimulation of the larynx by ingested matter produces a strong cough reflex to protect the lungs.

The vocal folds can be held close together (by adducting the arytenoid cartilages), so that they vibrate (see phonation). The muscles attached to the arytenoid cartilages control the degree of opening. Vocal fold length and tension can be controlled by rocking the thyroid cartilage forward and backward on the cricoid cartilage, and by manipulating the tension of the muscles within the vocal folds. This causes the pitch

produced during phonation to rise or fall. In most males the vocal cords are longer, producing a deeper pitch.

The vocal apparatus consists of two pairs of mucosal folds. These folds are false vocal cords(vestibular folds) and true vocal cords(folds). The false vocal cords are covered by respiratory epithelium, while the true vocal cords are covered by stratified squamous epithelium. The false vocal cords are not responsible for sound production, but rather for resonance. These false vocal cords do not contain muscle, while the true vocal cords do have skeletal muscle.

3.7 TRACHEA

The trachea, or windpipe, is the bony tube that connects the nose and mouth to the lungs, and is an important part of the vertebrate respiratory system. When an individual breathes in, air flows into the lungs for respiration through the windpipe. Because of its primary function, any damage incurred to the trachea is potentially life-threatening.

The bony skeletal trachea is comprised of cartilage and ligaments, and is located at the front of the neck. The trachea begins at the lower part of the larynx and continues to the lungs, where it branches into the right and left bronchi. It measures 3.9 to 4.7 inches (10-12 cm) in length, and .6 to .7 inches (16-18 mm) in diameter. The trachea is composed of 16 to 20 “c” shaped rings of cartilage connected by ligaments, with a ciliated-lined mucus membrane. It is this structure that helps push objects out of the airway should something become lodged.

Since it is connected to the same tubing system that allows an individual to swallow, the respiratory system has evolved a mechanism to prevent choking and respiratory failures. When an object blocks the trachea, choking occurs. The coughing reflex allows the ciliated cells to push the object out of the trachea and hence out of the respiratory system.

As the primary air canal in the vertebrate system, any damage incurred by the trachea could impair respiration. In the event of damage to the trachea, it may be necessary to undergo a procedure known as *intubation.* In this procedure, doctors place a tube in the nose or mouth and down to the trachea to get air to the lungs. The presence of fractures or inflammation in the trachea may require that a physician perform a *tracheotomy* to clear the airway. A tracheotomy, which is performed under general anesthesia, involves making a surgical incision in the throat area that creates a hole in the trachea through which a tube is inserted to provide ventilation.

Inflammation of the trachea can lead to other conditions, such as **tracheitis**, which is the inflammation of the linings of the trachea. **Tracheobronchitis** occurs when the mucous membrane of the trachea and bronchi become swollen, and **tracheomalacia** occurs when the connective nerve tissue in the trachea degenerates. Infections of the

trachea may result in what is referred to as **tracheomegaly**. A collapsed trachea, resulting from defects in the cartilage, which makes the cartilage unable to support the trachea, results in a dry hacking cough. To detect and treat abnormalities associated with the trachea, computer tomography scans, or CT scans, may be used.

3.8 LUNGS

The lungs are a pair of cone-shaped bodies that occupy the thorax . The mediastinum, the cavity containing the heart, separates the two lungs. The left and right lungs are divided by fissures into two and three lobes, respectively. Each lobe of the lung is further divided into bronchopulmonary segments (each with a tertiary bronchus), which are further divided into lobules (each with a terminal bronchiole). Blood vessels, lymphatic vessels, and nerves penetrate each lobe.

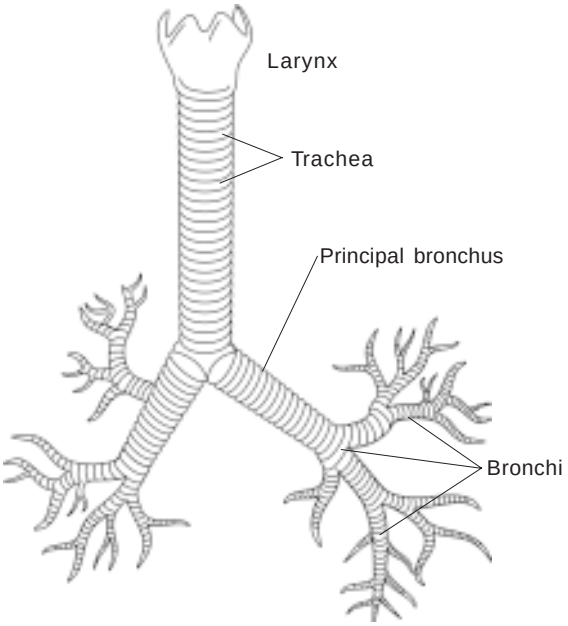


FIg. 3.8:

Each lung has the following superficial features:

The apex and base identify the top and bottom of the lung, respectively.

The costal surface of each lung borders the ribs (front and back).

On the medial (mediastinal) surface, where each lung faces the other lung, the bronchi, blood vessels, and lymphatic vessels enter the lung at the hilus.

The pleura is a double membrane consisting of an inner pulmonary (visceral) pleura, which surrounds each lung, and an outer parietal pleura, which lines the thoracic cavity. The narrow space between the two membranes, the pleural cavity, is filled with pleural fluid, a lubricant secreted by the pleura.

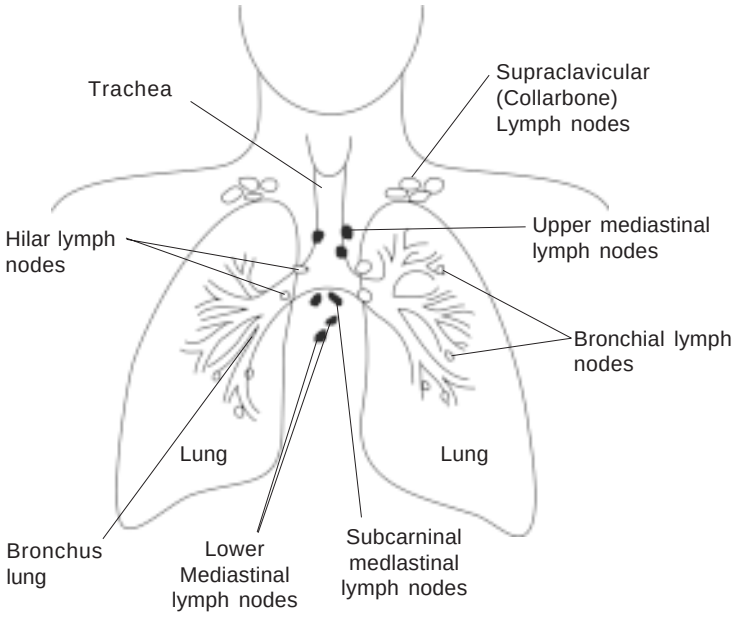


Fig. 3.9: Diagramnatic (view of lung)

A) Organization

The conducting zone contains the trachea, the bronchi, the bronchioles, and the terminal bronchioles.

The respiratory zone contains the respiratory bronchioles, the alveolar ducts, and the alveoli. The conducting zone and the respiratory zone (but not the alveoli) are made up of airways.

The conducting zone has no gas exchange with the blood, and is reinforced with cartilage and smooth muscle, which are very strong. Smooth muscle has variable resistance to air flow. The conducting zone warms the air to 37 degrees Celsius and humidifies the air. It also cleanses the air by removing particles.

The respiratory zone is the site of gas exchange with blood. The smooth muscle tone in bronchioles, and therefore bronchiolar diameter, is controlled by: the sympathetic nervous system via noradrenaline acting on the beta receptors and causes bronchodilation the parasympathetic nervous system via acetylcholine which acts on the muscarinic receptors and causes bronchoconstriction many other non-autonomic nervous and biochemical stimuli including, for example, carbon dioxide.

The intrapleural space is the potential space between the pleura lining the inner wall of the thoracic cage and the pleura lining the lungs.

B) Physiology

Total lung capacity (TLC) includes inspiratory reserve volume, tidal volume, expiratory reserve volume, and residual volume. The total lung capacity depends on the person's age, height, weight, sex, and normally ranges between 4,000 and 6,000 cm^3 (4 to 6 L). For example, females tend to have a 20–25% lower capacity than males. Tall people tend to have a larger total lung capacity than shorter people. Smokers have a lower capacity than nonsmokers. Lung capacity is also affected by altitude. People who are born and live at sea level will have a smaller lung capacity than people who spend their lives at a high altitude. In addition to the total lung capacity, one also measures the tidal volume, the volume breathed in with an average breath, about 500 cm^3. For a detailed discussion of the various lung volumes, see the article on lung volumes.

Typical resting adult respiratory rates are 10–20 breaths per minute with 1/3 of the breath time in inspiration.

Human lungs are to a certain extent 'overbuilt' and have a tremendous reserve volume as compared to the oxygen exchange requirements when at rest. This is the reason that individuals can smoke for years without having a noticeable decrease in lung function while still or moving slowly; in situations like these only a small portion of the lungs are actually perfused with blood for gas exchange. As oxygen requirements increase due to exercise, a greater volume of the lungs is perfused, allowing the body to reach its CO_2/O_2 exchange requirements.

C) Diseases

The following is a list of important medical conditions involving the lung. Many of these are caused or worsened by smoking.

Lung cancer

Emphysema is an enlargement of the air spaces in the lung, making it hard to breathe.

Asthma is an immunological disease which causes the bronchioles to narrow by inflammation and spasm of the lining of the airway wall.

Cystic fibrosis is a hereditary disease which causes the lung to produce abnormally viscous mucus.

A **pulmonary embolism** occurs when a blood clot obstructs an artery leading to the lung.

Tuberculosis is a transmittable bacterial infection of the lung, the most common infectious disease today.

Pneumonia is an infection of the lung, caused by bacteria, viruses or fungi.

Bronchitis is an inflammation of the bronchi.

A collapsed lung (pneumothorax) can occur when one or both walls of the pleural cavity are penetrated by injury, allowing air to enter.

In pulmonary edema, fluid from the capillaries enters the alveoli. This can be caused by weakness of the left side of the heart (resulting in a blood holdup in the lung), altitude sickness, or rarely inhaling toxic gases.

Lung pinprick condition is a hereditary disease, which results in decreased lung capacity and occasional shortness of breath.

3.9 DIAPHRAGM

The diaphragm is the primary muscle of inspiration. It is a thin, dome-shaped sheet of muscle that inserts into the lower ribs. When it contracts, it pushes downward and spreads out, increasing the vertical dimension of the chest cavity and driving up abdominal pressure. This increase in pressure drives the abdominal contents down and out, which in turn increases the transverse size of the chest cavity.

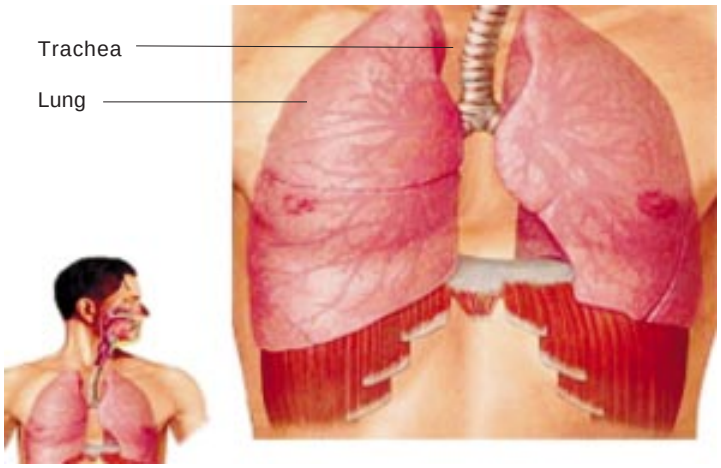
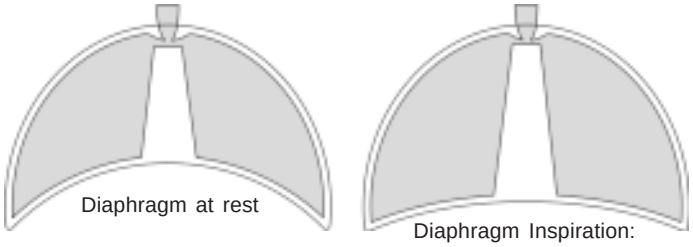


Fig. 3.10: Diaphragm.

Function movement of thoracic cage: Inspiration causes enlargement of thoracic cage. Increase in anteroposterior and transverse diameter occurs due to elevation of ribs. The vertical diameter of thoracic cavity is increased by descent of diaphragm.



Change in the size of thoracic cavity occurs because of the movement of four units of structures: thoracic lid, upper costal series, lower costal series and diaphragm.

Since the diaphragm is covered by the inferior surface of the parietal pleura, when it contracts, it pulls the pleura with it. This lowers the pleural pressure, which causes the alveolar pressure to drop, which, in turn, causes air to flow into the lungs. During quiet expiration, the diaphragm passively relaxes and returns to its equilibrium position. However, during exercise, expiration becomes an active process—the abdominal muscles contract to raise abdominal pressure, which pushes the diaphragm upward and forces air out of the lungs. During quiet breathing, the diaphragm moves a centimeter or two up and down, but during exercise, it can move more than 10 cm.

The diaphragm is supplied by the phrenic nerve from cervical segments 3, 4, and 5.

3.10 INTERCOSTAL MUSCLES

There are two sets of intercostal muscles. The external intercostals are found between the ribs with fibers running downward towards the sternum. They pull the ribs together, raising the rib cage during inspiration. The internal intercostals are also between the ribs. The fibers of the internals run at right angles to the external fibers. The action of the internal intercostals is to depress the rib cage during forced expiration.

Mechanism of Breathing

Ventilation is the term used for the movement to and from the alveoli. The two aspects of ventilation are **inhalation and exhalation** that are brought about by the **nervous system** and the **respiratory muscles.** The **respiratory centers** are located in the **brain stem.** The respiratory muscles are the **diaphragm** and the internal and external **intercostal muscles**. The diaphragm is a dune done shaped muscle below the lungs. When it contracts, the diaphragm flattens and moves downward. The intercostal muscles are found between the ribs. The external intercostal muscles pull the ribs upward and outward and the internal intercostal muscles pull the ribs downward and

inward. Ventilation is the result of the respiratory muscles producing changes in the pressure within the alveoli and bronchial tree.

There are three important pressures in respect to breathing:

Atmospheric pressure: The pressure of the air around us. At sea level the atmospheric pressure is 760 mmHg; at higher altitudes the pressure is lower.

Intrapleural pressure: The pressure within the potential pleural space between the parietal and visceral pleura. This space is a potential rather than a real space. Intrapleural pressure is always slightly below the atmospheric pressure. This is called negative pressure because the elastic lungs are always tending to collapse and pull the visceral pleura away from the parietal pleura. The serous fluid, however, prevents separation of the pleural membranes.

Intrapulmonic pressure: the pressure within the bronchial tree and alveoli. This pressure fluctuates below and above atmospheric pressure during each cycle of breathing.

Inhalation

Inhalation, also called inspiration, is a precise sequence of events.The nervous system sends an impulse to the diaphragm and external intercostal muscles. The diaphragm flattens, which increases top-to-bottom length of the thorax. Contraction elevates the ribs and increases the size of the thorax from the front to the back and from side to side. This increase in the size of chest cavity reduces the pressure within it, and what follows is an active process where air moves into the lungs.

Exhalation

Quiet expiration is ordinarily a passive process. During expiration, the thorax returns to its resting size and shape. Elastic recoil of lung tissues aids in expiration. However, expiratory muscles used in forceful expiration are the internal intercostals and abdominal muscles. Reduction of the size of the thoracic cavity builds pressure and air leaves the lungs.

3.11 PULMONARY AIR VOLUMES

Pulmonary function tests are useful in the assessing the functional status of respiratory system, both in physiological and pathological conditions. Air in lung is classified into two divisions:

A) Lung volumes

(*i*) *Tidal volume* (*TV*): The volume of the air breathed in and out of the lungs in normal quite respiration is called TV. It signifies normal depth of breathing. Its normal value is 500 ml.

(*ii*) *Inspiratory reserve volume* (*IRV*): An additional amount of air that can be inspired forcefully after the end of normal inspiration beyond TV is called the IRV. Its normal value is 3300 ml.

(*iii*) *Expiratory reserve volume* (*ERV*): The additional amount of air that can be expired out forcefully after normal expiration is called ERV. Its normal value is 1000ml.

(*iv*) *Residual volume* (*RV*): Normally, lungs cannot be emptied completely even after forceful expiration. Some amount of air always remains in the lungs even after the forced expiration. The amount of air remaining is called RV.

It helps to aerate the blood in between breathing and during expiration, and also maintains the contour of the lungs. Its normal value is 1200 ml.

B) Lung Capacities

Two or more lung volumes together are called lung capacities. These are of four types:

(*i*) *Inspiratory Capacity* (*IC*): It is the maximum volume of air that is inspired from end expiratory position. Inspiratory capacity includes tidal volume and inspiratory reserve volume.

IC = TV + ERV
500 + 3300 = 3800 ml.

(*ii*) *Vital Capacity* (*VC*): It is the maximum amount of air that is expelled out forcefully after a maximal(deep) inspiration. It includes inspiratory reserve volume, tidal volume and expiratory reserve volume.

VC = IRV + TV + ERV
3300 + 500 + 1000 = 4800 ml.

(*iii*) *Functional Residual Capacity* (*FRC*): It is the volume of air remaining in the lungs after normal expiration (after normal tidal expiration). It includes expiratory reserve volume and reserve volume.

FRC = ERV + RV
1000 + 1200 = 2200

(*iv*) *Total Lung Capacity* (*TLC*): It is the amount of air present in the lungs after a maximal(deep) inspiration. It includes all volumes.

TLC = IRV + TV + ERV + RV

3300 + 500 + 1000 + 1200 = 6000 ml.

3.12 PARTIAL PRESSURE

Gases are transported across the alveolar wall between the alveoli and pulmonary capillary blood by the process of simple passive diffusion. Generally, the driving force for movement by diffusion is concentration difference or concentration gradient. However, when discussing the movement of gases, concentration is not the appropriate measure of driving force. This is because, when dissolved in body fluids, much of the gas may be immobilized by binding (e.g., O_2 to hemoglobin) or transformed into another chemical form (e.g., CO_2 to bicarbonate). Thus, the use of concentration would give an erroneously high force for diffusion, since concentration (or content) includes bound molecules which are not free to diffuse. So when discussing movement of gases, we require some more accurate measure of tendency to diffuse; such a measure is given by partial pressure.

Definition. The partial pressure of a given gas is defined as the pressure exerted by that gas alone. For example, consider the gaseous mixture of oxygen, nitrogen, carbon dioxide, and water vapor, the typical mixture found in alveolar gas. If this mixture was enclosed in a sealed container, it would develop a pressure on the walls of the container by the mechanism of collision between the gas molecules and the container walls. The force or pressure developed by all the molecules of the mixture, as they bounce off the container walls, is the total pressure exerted by the gas. The partial

pressure of any component is the pressure developed by the molecules of that component acting alone. That is, the partial pressure of oxygen is the pressure developed by the oxygen molecules, the partial pressure of nitrogen is the pressure developed by nitrogen molecules, and similarly for the other components of the mixture. Clearly, the sum of the partial pressures of the individual components must equal the total pressure on the container walls.

We could measure the partial pressure of any component by removing the other components and determining the remaining pressure. Thus, the partial pressure of oxygen could be measured by removing nitrogen, carbon dioxide, and water vapor, and determining the pressure resulting from the remaining oxygen molecules. This is a tedious procedure, which we can circumvent, either by the use of other types of measuring instruments (special electrodes, etc.), or by calculation using the following rules.

Calculation of Partial Pressures

Gas mixtures. In a mixture of gases, the partial pressure of a given gas is directly proportional to the volume that gas contributes to the total volume. That is, if we define the fraction of any gas, F_x, as the ratio of the volume of that gas, V_x to the total volume of all gases:

$$F_x = V_x/V_{total} \quad (1)$$

then the partial pressure contributed by that gas, P_x, is simply that fraction multiplied by the total pressure, or

$$P_x = F_x \cdot P_{total} \quad (2)$$

For example, dry air is composed of approximately 21% oxygen (actually 20.9%), and 79% nitrogen (actually, nitrogen is closer to 78%, with the remaining 1% consisting mainly of argon; for purposes of respiration, we usually lump the inert gases with nitrogen). Assuming 21% O_2 and 79% N_2 and assuming the standard barometric pressure of 760 mmHg, the partial pressure of these gases is

$$P_{O_2} = 0.21 \cdot 760 = 160 \text{ mmHg}$$

$$P_{N_2} = 0.79 \cdot 760 = 600 \text{ mmHg}$$

Note that it follows from equations (1) and (2) that the sum of the partial pressures must equal the total barometric pressure (in the above example, 160 + 600 = 760).

Vapors. When a gas is in contact with a liquid, and is in equilibrium (saturated) with the liquid, the partial pressure of the gas is a function of temperature. The one gas to which this applies in a normal respiration is water. The lungs and airways are always

moist, and inspired gas is rapidly saturated with water vapor in the upper segments of the respiratory system. The temperature in the airways and lungs is almost identical with deep body temperature (approximately 37°C); at this temperature water vapor has a partial pressure of 47 mmHg. (Note that the gaseous form of a liquid frequently is termed a "vapor").

Using the value of 47 mmHg, we can calculate the partial pressure of oxygen and nitrogen in inspired air, after the gas mixture becomes saturated with water vapor in the upper airway (so-called tracheal air):

P_{total} = 760 mmHg

P_{H_20} = 47 mmHg

713 mmHg for remaining inspired gases (21% O_2 and 79% N_2)

$P_{O_2} = 0.21 \cdot 713 = 150$ mmHg

$P_{N_2} = 0.79 \cdot 713 = 563$ mmHg

That is, since water vapor partial pressure must be 47 mmHg in a saturated gas mixture at 37°C, the total pressure remaining for the inspired gases is only 760-47 or 713 mmHg. The composition of this remaining gas is 21% O_2 and 79% N_2, giving the partial pressures indicated above.

Dissolved gases. When a gas is dissolved in a liquid, its partial pressure is determined by the components of the solution that bind or combine with the gas, and the total content or concentration of the gas in the liquid. Such a relation between partial pressure and content is termed saturation or dissociation curve. Each gas has a particular saturation curve determined by the physical and chemical properties of the solution. While discussing the transport of gases in the blood, one must consider in detail the saturation curves for oxygen and carbon dioxide.

In a gas mixture, the partial pressure of each component is determined by the composition of the mixture. For a gas in equilibrium with its liquid state, partial pressure is determined by the characteristics of the liquid and its temperature. The partial pressure of each gas in solution is related to the content or concentration of that gas by the particular dissociation curve.

Onchi, and Bronchioles

3.13 GASEOUS EXCHANGE IN LUNGS

Respiratory gaseous exchange occurs between the interior of an organism and the environment. In all animals with a vascular system, in which the **blood** transports respiratory gases, there is a two fold gaseous exchange within actively respiring tissues

and the respiratory **organs**. In humans, the respiratory organs are the **lungs**, and there gaseous exchange takes place in the **alveoli**.

The quantity of gas diffusing through the alveolar **tissue** depends on pressure differences. There are pressure gradients between the air in the alveoli and the blood. The steeper the gradient, the more rapid the gaseous exchange. The steepness of the pressure gradient corresponds to the difference between the partial pressure of the respiratory gas in the alveolar air and its partial pressure in the blood (the pressure exerted by a particular component of a mixture of gases is called the partial pressure of that gas). Inspired air contains 21 vol% of oxygen which corresponds to a partial pressure of 21.3 kPa. After mixing with the air in the lungs, this partial pressure falls to about 13 kPa. In contrast, the oxygen partial pressure of the venous blood delivered to the lung **capillaries** by the lung **arteries** is about 5kPa. After passage through the lung capillaries, the oxygen partial pressure of the blood rises to about 13 kPa. As the total volume of oxygen in the lungs is large compared with the volume that diffuses into the blood, the oxygen partial pressure of the alveolar air decreases only slightly. In the pulmonary vein to the **heart**, the oxygen concentration decreases somewhat, because it is mixed with "short circuited" blood, which passed through the lungs, but does not take part in gaseous exchange. The final oxygen partial pressure of arterial blood is about 12 kPa.

In the organism, carbon dioxide diffuses in the opposite direction to oxygen. The carbon dioxide partial pressure of inspired air increases from 0.03-5.3 kPa on mixing with pulmonary air. By gaseous exchange, the carbon dioxide partial pressure of the blood decreases from 6 to 5 kPa during passage through the lung capillaries. Carbon dioxide diffuses much more rapidly than oxygen, so that carbon dioxide exchange is completed before the **oxygen exchange**.

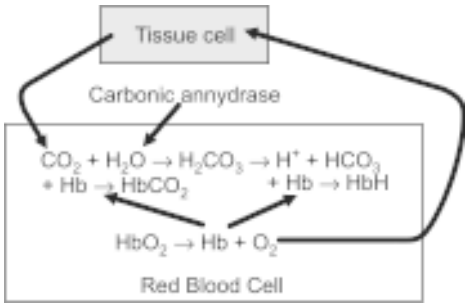
Gaseous exchange in the tissues also depends on diffusion. The direction of diffusion of the two respiratory gases is the reverse of that in the lungs. In tissue cells, oxygen partial pressure varies between 0 and 4 kPa, and that of carbon dioxide between 6.7 and 8 kPa. The rate of gaseous exchange in tissues depends on two factors—the metabolic activity of the tissue and the dilation of blood vessels. Metabolic activity can alter the pressure gradients of oxygen and carbon dioxide between the tissue and the blood, while the dilation of the blood vessels causes an increase in blood flow through the tissue and enhances the rate of gaseous exchange by increasing the diffusion factor.

3.14 TRANSPORT OF RESPIRATORY GASES IN BLOOD

The gases are carried in the blood in two forms: dissolved in the plasma or combined with hemoglobin.

Hemoglobin within the red blood cells is able to combine rapidly and reversibly with oxygen to dramatically increase the solubility of oxygen in blood. Consider that the typical cardiac output is 5L blood/min and resting oxygen consumption is 250 mL/min. Because of the low solubility of oxygen in aqueous solution, only 3 mL of O_2 will dissolve in the plasma fraction of 1 L of arterial blood. Therefore, only 15mL of dissolved O_2 reaches the systemic circulation each minute—not nearly enough to meet normal metabolic demands. Under normal circumstances, more than 98% of the oxygen in a given volume of blood is transported in RBCs, bound to hemoglobin. The amount of oxygen that binds to hemoglobin depends on the PO_2 of the plasma surrounding the RBCs and the number of available binding sites within the RBC. The number of potential binding sites depends largely on the total number of hemoglobin molecules in the blood.

Oxygen (O_2) forms a rapid and reversible combination with hemoglobin (Hb) to give oxyhemoglobin (HbO_2). This relationship is represented by the Oxygen-Hemoglobin dissociation curve. Note that the amount of oxygen carried by hemoglobin rapidly increases to a PO_2 of 50 mm Hg, but above that the curve flattens out. This represents the oxygen capacity, the maximum amount of oxygen that can be combined with hemoglobin.


Tissue cell
Carbonic annydrase
$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3$
$+ Hb \rightarrow HbCO_2$
$+ Hb \rightarrow HbH$
$HbO_2 \rightarrow Hb + O_2$
Red Blood Cell

3.15 KINDS OF RESPIRATION

External Respiration

This is exchange of gases by diffusion between the alveoli and the blood in the alveolar capillaries, across the respiratory membrane. Each alveolar wall is one cell thick and is surrounded by a network of tiny capillaries.

Venous blood traveled from allover the body contains high levels of CO_2 and low levels of O_2. CO_2 diffuses from venous blood down its concentration gradient into alveolus until an equilibrium with the air is reached. And O_2 diffuses from the alveoli into the blood.

Internal Respiration

This is exchange of gases by diffusion between blood in the capillaries and the body cells. As the walls of the arteries coming from the heart are too thick, no exchange occurs and hence PO_2 remains same from lungs to tissues. Carbon dioxide is cleansed for the blood arriving at the tissues and saturated with O_2 and hence has higher PO_2 and lower PCO_2. O_2 diffuses from the blood stream through the capillary wall into the tissues and CO_2 from the cells into the extracellular fluid, then into bloodstream towards the venous end of the capillary.

Cellular Respiration: Cellular respiration is the process of moving energy from one chemical form (glucose) into another (ATP), since all cells use ATP for all metabolic reactions. First the oxygen must diffuse from the alveolus into the capillaries. It is able to do this because the capillaries are permeable to oxygen. The other oxygen will bind to red blood cells. Blood with hemoglobin is able to transport 26 times more oxygen than plasma without hemoglobin. Our bodies would have to work much harder pumping more blood to supply our cells with oxygen without the help of hemoglobin. Once it diffuses by osmosis it combines with the hemoglobin to form oxyhemoglobin. As cells take apart the carbon molecules from glucose, these get released as carbon dioxide. Each body cell releases carbon dioxide into nearby capillaries by diffusion, because the level of carbon dioxide is higher in the body cells than in the blood. In the capillaries, some of the carbon dioxide is dissolved in plasma and some is taken by the hemoglobin, but most enters the red blood cells where it binds with water to form carbonic acid. It travels to the capillaries surrounding the lung where a water molecule leaves, causing it to turn back into carbon dioxide. It then enters the lungs where it is exhaled in aerobic respiration.

Aerobic Respiration: Requires oxygen in order to generate energy (ATP). It is the preferred method of pyruvate breakdown from glycolysis and requires that pyruvate enter the mitochondrion to be fully oxidized by the Krebs cycle. The product of this process is energy in the form of ATP (Adenosine Triphosphate), by substrate-level phosphorylation, NADH and $FADH_2$.

Anaerobic Respiration: Without oxygen, pyruvate is not metabolized by cellular respiration but undergoes a process of fermentation. The pyruvate is not transported into the mitochondrion, but remains in the cytoplasm, where it is converted to waste products that may be removed from the cell. This serves the purpose of oxidizing the hydrogen carriers so that they can perform glycolysis again and removing the excess pyruvate. This waste product varies depending on the organism. In skeletal muscles, the waste product is lactic acid. This type of fermentation is called lactic acid fermentation. In yeast, the waste products are ethanol and carbon dioxide. This type

of fermentation is known as alcoholic or ethanol fermentation. The ATP generated in this process is made by substrate phosphorylation, which is phosphorylation that does not involve oxygen.

Equation: $C_6H_{12}O_{6(aq)} + 6O_{2(g)} \rightarrow 6CO_{2\,(g)} + 6H_2O_{(l)}\ \Delta H_c$ –2880 kJ

3.16 ARTIFICIAL BREATHING/RESUSCITATION

A) Definition: When an individual stops breathing, he will soon die if the tissues of the body, particularly the brain, do not get a fresh supply of oxygen. Various mechanical devices are sometimes used to maintain breathing.

B) Methods: One is the *pulmotor*. Second is In "*mouth-to-mouth*" *resuscitation*, in which the operator forces air from his own respiratory system into the respiratory system of the patient. Fortunately, the initial air forced into the patient is the "dead air" of the operator and still has its full amount of oxygen. There are various techniques for manipulating the patient's rib cage to simulate normal function. At times, gravity may be used to assist a patient. In particular postures, a patient may find breathing easier. Also, under certain circumstances, a patient may be positioned to drain accumulated fluids from specific parts of the lungs. **Manual methods** include Holger nelson method and **Mechanical methods** includes Drinker method, which creates positive or negative pressure according to the requirement in which an ironlung chamber is utilized.

3.17 RESPIRATORY ADJUSTMENTS IN EXERCISE

A) Hyper ventilation

It means increased pulmonary ventilation due to forced breathing also called over ventilation. Here, both the rate and force of breathing are increased and a large amount of air moves in and out of the lungs. Thus, pulmonary ventilation is increased to a great extent.

Factors affecting hyper ventilation: Mostly occurs in conditions like exercise when partial pressure of carbon dioxide is increased. Excess of CO_2 stimulates the respiratory centers. Voluntarily also, hyperventilation can be produced by increasing rate and depth of breathing called voluntary hyperventilation.

Effects: Excessive CO_2 is washed out and in blood partial pressure of CO_2 is reduced. Very often it leads to dizziness, discomfort and chest pain.

B) Respiratory Quotient

Definition: It is the molar ratio of carbon dioxide production to oxygen consumption. It is used to determine the utilization of different food stuffs. For about one hour after

meals the respiratory quotient is 1.0, as immediately after taking meals, carbohydrates are utilized by the tissues. During the metabolism of carbohydrates, one molecule of CO_2 is produced for every one molecule of O_2 consumed by the tissues. When body starts utilizing fats, RQ value becomes 0.7. When proteins are metabolized, it becomes 0.8 During exercise RQ value increases.

3.18 SOME RESIRATORY DISORDERS

Cold: Common cold is usually caused by the Rhinoviruses and is highly infectious. Symptoms are runny nose(rhinorrhoea), sneezing, sore throat and sometimes slight fever. Normally, a cold runs its course over a few days.

Pneumonia: It is the inflammation of lung tissues followed by the accumulation of blood cells, fibrin and exudates in the alveoli. Affected part of the lungs becomes consolidated. It is could mainly by bacterial or viral infection or due to inhaling noxious chemicals. **Symptoms** may be fever, compression of chest and chest pain, shallow breathing, cyanosis, sleeplessness (insomnia), delirium(extreme mental conditions due to cerebral hypoxia like confused state of mind, illusion or loss of memory etc).

Tuberculosis (TB): This infection is caused by one of the two similar forms of mycobacteria, the main being *Mycobacterium tuberculosis*. Humans are the main host. Microbes cause pulmonary tuberculosis and spread either by droplet infection from an individual with active tuberculosis or in dust contaminated by infected sputum. **Symptoms** may be weight loss and malaise develop insidiously. Night sweats are common. Chronic cough, with or without blood in the sputum (haemptysis), may be present.

Phases of Pulmonary Tuberculosis

Primary tuberculosis: When microbes are inhaled, they colonize a lung bronchiole and there may be no evidence during the initial stage of inflammation. But later cell mediated T-lymphocytes produce antigens and individual become sensitized.

Secondary tuberculosis: This occurs in people carrying primary lesion and may be caused by a new infection or by reactivation of infection by microbes surviving often following reduction in the immunity due to age or illness.

Asthma: It is an inflammatory disease of the air ways associated with episodes of reversible over reactivity of the airway smooth muscle. The mucous membrane and the mucous glands of the bronchi become thickened and the mucous glands enlarge, reducing airflow in the lower respiratory tract. Inspiration is normal but only partial expiration is achieved, so the lungs become hyperinflated and there is a severe dypnoea and wheezing.

Non-specific factors include—cold air, cigarette smoking, air pollution, upper respiratory tract infection, emotional stress and strenuous exercise. Clinically there are two types

of Asthma (i) Childhood(atopic) where allergen is the affending agent. (ii) Lateonset occurs 1st time when the person is fully adult. **Symptoms** are dyspnea expiration becomes difficult classical wheeze etc.

Lung Emphysema: It is one of the obstructive diseases in which the lung tissues are extensively damaged. It is **caused by** cigarette smoking, exposure to oxidant gases and untreated bronchitis. **Clinical features** are loss of elasticity of the lungs, amplitude of individual respiratory excursion is small, breathlessness after even little exertion finally breathlessness at rest develop. During inspiration elastic fibres get streached and contraction of the inspiratory muscles ceases, recoil occurs, lungs shrinks and the air from the lung is expelled.

Lung Abscess: This is localized suppuration and necrosis within the lung substance. Sources of infection may be inhalation of respiratory secretions or gastric contents, inadequately treated pneumonia, traumatic penetration of lung e.g., Rib fracture, stab or gunshot wound or during surgery, allowing pathogens to enter the lungs, local spread of infection e.g., Pleural cavity, oesophagus etc. Outcomes Recovery may either complete or complications like chronic suppuration, septic emboli,subpleural abscesses may spread and cause emphysema, erosion of pulmonary blood vessel leading to haemorrhage.

CONTROL OF RESPIRATION: This is normally involuntary. Voluntary control is exerted during activities such as speaking and singing but is overridden if blood CO_2 rises (hypercapnia).

Respiratory centre: This is formed by group of nerves in medulla, the respiratory rhythmicity centre, which control the respiratory pattern, i.e., the rate and depth of breathing. Regular discharge of inspiratory neurons within this centre set the rate and depth of breathing. Activity of the respiratory rhythmicity centre is adjusted by nerves in the pons, in response to input from other parts of the brain.

Motor impulses leaving the respiratory centre pass in the phrenic and intercostals nerves to the diaphragm and intercostal muscles respectively.

CHAPTER 4

Circulatory System

"A circuit of circulation
Performs transportation
Manages both gas and ion concentration"

4.1 INTRODUCTION

The **circulatory system** (also called the **cardiovascular system**, in vertebrates) is an organ system that moves blood and lymph *to and from* the cells of the body through a network of hollow vessels. The circulation of blood brings oxygen and food molecules to cells, and removes carbon dioxide and the waste products of metabolism from them. Blood circulation also helps stabilize the body temperature and pH (part of homeostasis). The circulatory system provides for the widespread transportation of immune cells and antibodies that fight germs and toxins, as well as the transport of hormones and other signal molecules that have functions throughout the body. The circulation of lymph is particularly important for the body's absorption of fat from the small intestine, and the movement of excess fluid as well as white cells and proteins. The lymph and blood circulations are connected and the contents of both sets of vessels are ultimately moved by the pumping of the heart. The main components of the circulatory system are the heart, the blood, and the blood vessels, the lymph and the lymphatic vessels. The blood and lymphatic circulations are connected, and account for the entire systemic circulation. Circulatory system gives an overview of the patterns of blood and lymph flow in the vertebrate body.

Circulatory system in the body is formed by solids and fluids. The fluid part is more than 2/3 of the whole body. Water content varies from 45 to 75% of body weight. In a normal young adult male, body contains 60 65% water and 30-40% of solids. And in case of female, the water is 50 to 55% and solids are 45-50%. In females, water is less because of more amount of subcutaneous adipose tissue.

The two systems communicate with one another and are intimately associated with each other. The heart pumps blood into two anatomically separate systems of blood vessels:

- The pulmonary circulation
- The systemic circulation.

The right side of the heart pumps the blood into the lungs (pulmonary circulation) where gas exchange occurs, i.e., CO_2 leaves the blood and enters the lungs, and O_2 leaves the lungs and enters the blood. The left side of the heart pumps the blood into the systemic circulation, which supplies the rest of the body. Here, tissue wastes are passed into the blood for extraction, and body cells extract nutrients and O_2. The circulatory system ensures continuous flow of blood to all body cells and its function is subject to continual physiological adjustments in order to maintain an adequate blood supply.

4.2 BLOOD

The blood volume in the body varies according to the size of an individual. The blood accounts for about 7 per cent of the body weight. The blood is an intricate part of the circulatory system. Since the body systems are always changing the balance of the blood, it tries to keep the body in an equilibrium state. Its major function is to transport all the vital substances necessary to maintain bodily life processes.

Each cell must receive oxygen and nutrients if cell life is to be maintained. The oxygen and nutrients, the cells use to carry out their functions, produce waste that must be removed. The blood also transports hormones from the different glands located throughout the body. These hormones act as messengers that depend on the blood for travel. Another function is to help us keep immune from diseases that may enter the body. If you have ever been cut, thank your blood for its ability to clot. The clotting process not only stops you from bleeding to death, but also assists in stopping microbes from entering and causing infection.

A) Composition of Blood

Blood is composed of straw colored transparent fluid, plasma, in which different types of cells are suspended. Plasma constitutes about 55% and cells about 45% of blood volume.

Plasma

The constituents of plasma are water (90 to 92%) and dissolved substances including:

- plasma proteins;
- inorganic salts;
- nutrients, principally from digested foods;
- waste materials;
- hormones; and
- gases.

Plasma proteins

Plasma proteins make-up about 7% of plasma. They are normally retained within the blood, because they are too big to escape through the capillary pores into the tissues. They are largely responsible for causing osmotic pressure of blood (normally 25mm of Hg or 3.3KPa), which keeps the plasma fluid within the circulation. If plasma protein levels fall, because of either reduced production or loss from the blood vessels, osmotic pressure is also reduced and fluid moves into the tissues (oedema) and body cavities.

- **Albumins** are formed in the liver. They are the most abundant plasma proteins and their main function is to maintain normal plasma osmotic pressure. They also act as carrier molecule for lipids and steroid hormones.
- **Globulins** are formed in the liver and the remainder in the lymphoid tissue. Their main functions are:
    1. As antibodies (immunoglobulins), which are complex proteins produced by lymphocytes that play an important role in immunity.
    2. Transportation of some hormones and mineral salts; e.g., thyroglobulin carries the hormone thyroxine, and transferrin carries the mineral iron.
    3. Inhibition of some proteolytic enzymes. e.g., alpha macroglobulin inhibits trypsin activity.
- **Clotting factors** are the substances essential for coagulation of blood. Serum is a plasma from which clotting factors have been removed.

Fibrinogen is synthesized in liver and is essential for blood coagulation.

Inorganic salts These are involved in a wide variety of activities like muscle contraction, transmission of nerve impulses, formation of secretions and maintenance of acid-base balance, the PH, which is the measure of hydrogen ion concentration, or {H+).

The PH of blood is maintained between 7.35 and 7.45 by an ongoing complicated series of chemical activities involving buffering systems.

Nutrients In the alimentary tract, food is broken down into small molecules, e.g, monosaccharides, amino acids, fatty acids and glycerol is absorbed. Organic salts are required by all body cells to provide energy, heat, materials for repair and replacement and for the synthesis of other blood components and body secretions.

Waste products Urea, creatinine and uric acid are the waste products of protein metabolism. They are formed in the liver and conveyed in the blood to the kidneys for excretion.

Hormones These are the substances synthesized by endocrine glands. Hormones pass directly from the endocrine cells into the blood, which transports them to their target tissues and organs in the body where they influence cellular activity.

Gases Oxygen, carbon dioxide and nitrogen are transported round the body dissolved in plasma. Oxygen and carbon dioxide are also transported in combination with haemoglobin in RBC. Atmospheric nitrogen enters the body in the same way as other gases and is present in plasma of but it has no physiological function.

B) Structure of Blood

Two types of blood vessels carry blood throughout our bodies: The arteries carry oxygenated blood (blood that has received oxygen from the lungs) from the heart to the rest of the body. The blood then travels through the veins back to the heart and lungs, where it receives more oxygen. As the heart beats, you can feel blood traveling through the body at your pulse points—like the neck and the wrist—where large, blood-filled arteries run close to the surface of the skin.

The blood that flows through this network of veins and arteries is called **whole blood**. Whole blood contains three types of blood cells:

1. **Red blood cells**
2. **White blood cells**
3. **Platelets.**

These three types of blood cells are mostly manufactured in the bone marrow (the soft tissue inside our bones), especially in the bone marrow of the vertebrae (the bones that make up the spine), ribs, pelvis, skull, and sternum (breastbone). These cells travel through the circulatory system suspended in a yellowish fluid called **plasma** (pronounced: **plaz**-muh). Plasma is 90% water and contains nutrients, proteins, hormones, and waste products. Whole blood is a mixture of blood cells and plasma.

Red blood cells (also called **erythrocytes**) These are shaped like slightly indented, flattened disks. These contain an iron-rich protein called **hemoglobin**. Blood gets its bright red color when hemoglobin in red blood cells picks up oxygen in the lungs. As the blood travels through the body, the hemoglobin releases oxygen to the tissues. The body contains more red blood cells than any other type of cell, and each red blood cell has a life span of about 4 months. Each day, the body produces new red blood cells to replace those that die or are lost from the body.

The red blood cells are tiny, round, biconcave disks, averaging about 7.5 microns (0.003 in) in diameter. A normal-sized man has about 5 l (5.3 qt) of blood in his body, containing more than 25 trillion red cells. Since the normal life span of red cells in the circulation is only about 120 days, more than 200 billion cells are normally destroyed each day by the spleen and must be replaced. Red blood cells, as well as most white cells and platelets, are made by the bone marrow.

The main function of the red blood cells is to transport oxygen from the lungs to the tissues and to transport carbon dioxide, one of the chief waste products, to the lungs for release from the body.

The substance in the red blood cells that is largely responsible for their ability to carry oxygen and carbon dioxide is **hemoglobin**, the material that gives the cells their red color. It is a protein complex comprising many linked amino acids, and occupies almost the entire volume of a red blood cell. Its functional part is the mineral ion. the mineral,iron.

White blood cells (also called **leukocytes**) These are a key part of the body's system for defending itself against infection. They can move in and out of the bloodstream to reach affected tissues. The blood contains far fewer white blood cells than red cells, although the body can increase the production of white blood cells to fight infection. There are several types of white blood cells, and their life spans vary from a few days to months. New cells are constantly being formed in the bone marrow.

Several different parts of blood are involved in fighting infection. White blood cells called **granulocytes** and **lymphocytes** (pronounced: **lim**-fuh-sytes) travel along the walls of blood vessels. They fight germs such as bacteria and viruses and may also attempt to destroy cells that have become infected or have changed into cancer cells.

Certain types of white blood cells produce antibodies, special proteins that recognize foreign materials and help the body destroy or neutralize them. When a person has an infection, his or her white cell count (the number of cells in a given amount of blood) is often higher than when he or she is well because more white blood cells are being produced or are entering the bloodstream to battle the infection. After the body has been challenged by some infections, lymphocytes "remember" how to make the specific antibodies that will quickly attack the same germ if it enters the body again.

Platelets (also called **thrombocytes**, pronounced: **throm**-buh-sytes) These are tiny oval-shaped cells produced in the bone marrow. They help in the clotting process. When a blood vessel breaks, platelets gather in the area and help seal off the leak. Platelets survive only about 9 days in the bloodstream and are constantly being replaced by new cells.

Blood also contains important proteins called **clotting factors**, which are critical to the clotting process. Although platelets alone can plug small blood vessel leaks and temporarily stop or slow bleeding, the action of clotting factors is needed to produce a strong, stable clot.

Platelets and clotting factors work together to form solid lumps to seal leaks, wounds, cuts, and scratches and to prevent bleeding inside and on the surfaces of our bodies. The process of clotting is like a puzzle with interlocking parts. When the last part is in place, the clot happens, but if only one piece is missing, the final pieces can't come together.

When large blood vessels are severed (or cut), the body may not be able to repair itself through clotting alone. In these cases, dressings or stitches are used to help control bleeding.

In addition to the cells and clotting factors, blood contains other important substances, such as nutrients from the food that has been processed by the digestive system. Blood also carries hormones released by the endocrine glands and carries them to the body parts that need them.

Blood is essential for good health because the body depends on a steady supply of fuel and oxygen to reach its billions of cells. Even the heart couldn't survive without blood flowing through the vessels that bring nourishment to its muscular walls! Blood also carries carbon dioxide and other waste materials to the lungs, kidneys, and digestive system, from where they are removed from the body.

An interesting thing about blood is that blood cells and some of the special proteins blood contains can be replaced or supplemented by giving a person blood from someone else. This process is called transfusion. In addition to receiving whole blood transfusions, people can also receive transfusions of a particular component of blood that they need. For example, a person can receive only platelets, red blood cells, or a clotting factor. When a person donates blood, the whole blood can be separated into its different parts and used in this way.

Platelets or **thrombocytes** These are much smaller than the red blood cells. They are round or biconcave disks and are normally about 30 to 40 times more numerous than the white blood cells. The platelets' primary function is to stop bleeding. When the tissue is damaged, the platelets aggregate in clumps to obstruct the blood flow.

Like red blood cells, platelets in mammals are anuclear (no cell nucleus) and discoid (disc shaped); they measure 1.5–3.0 μm in diameter. The body has a very limited reserve of platelets, so they can be rapidly depleted. They contain RNA, mitochondria, a canalicular system, and several different types of granules: lysosomes (containing acid hydrolases), dense bodies (containing ADP, ATP, serotonin, histamine, and calcium) and alpha granules (containing fibrinogen, factor V, vitronectin, thrombospondin and von Willebrand factor). The contents of the granules are released upon activation of the platelet.

Functions of platelets can be generalised into a number of categories:

1. Adhesion
2. Aggregation
3. Clot retraction
4. Pro-coagulation
5. Cytokine signalling
6. Phagocytosis.

C) Functions of Blood

Cells are continously adding waste products, secretions and metabolites to the blood, while taking from it vital nutrients, oxygen, hormones and other substances. The adult human has about seven to five liters of blood. Without blood, the human body would stop working and consequently die. Have you ever imagined what life would be like without blood. We will have a pictorial mental image of what a life on Earth will be like if there is no blood in the human body. Obviously blood is life. Blood is the medium for the transport of digested and absorbed materials throughout the human body. Below are some of the functions of blood.

1. Blood helps to transport food nutrients to various tissues for utilization.
2. Blood also helps in the transportation of waste products of metabolism such as urea, uric acid, etc from tissues where there are produced to the kidney for excretion.
3. The red blood cell, which is a cellular part of the blood, helps to transport respiratory gases such as oxygen from the lungs to actively metabolizing tissues.
4. Hormones secreted by the endocrine glands are transported to target organs via the blood.
5. The white blood cells help to protect out body against foreign agents such as bacteria and viruses.

6. The blood helps in the even distribution of heat generated by actively metabolizing tissues such as the liver and muscles to cooler parts of the body.
7. The plasma proteins help to maintain the pH of the body fluid.
8. The oncotic pressure of the plasma proteins helps to control the exchange of fluids between the capillaries and the tissues.

The blood is a very precious fluid, so try and handle it with care!

4.3 BLOOD GROUPS

The differences in human blood are due to the presence or absence of certain protein molecules called antigens and antibodies. The antigens are located on the surface of red blood cells and the antibodies are present in the blood plasma. Individuals have different types and combinations of these molecules. The blood group you belong to depends on what you have inherited from your parents.

There are more than 20 genetically determined blood group systems known today, but the AB0 and Rh systems are the most important ones used for blood transfusions. Not all blood groups are compatible with each other. Mixing incompatible blood groups leads to blood clumping or agglutination, which is dangerous for individuals.

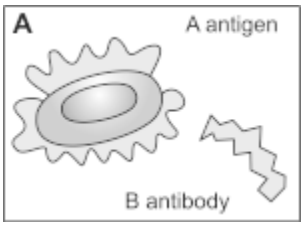
Nobel Laureate Karl Landsteiner was involved in the discovery of both the AB0 and Rh blood groups.

A) The ABO Blood Groups

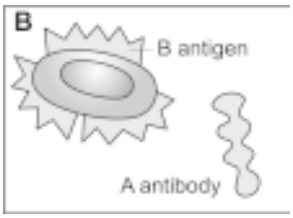
The ABO blood groups were the first to be discovered (in 1900) and are the most important in assuring safe blood transfusions. According to the AB0 blood typing system, there are four different kinds of blood types: A, B, AB or 0 (null).

If you belong to the blood group A, you have A antigens on the surface of your red blood cells and B antibodies in your blood plasma.

Blood group A

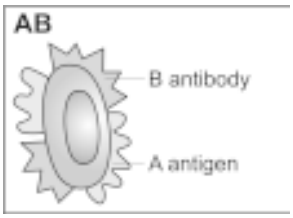


Blood group B



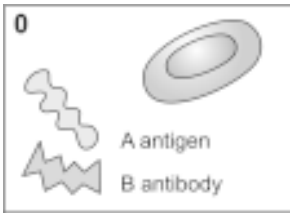
If you belong to the blood group B, you have B antigens on the surface of your red blood cells and A antibodies in your blood plasma.

Blood group AB



If you belong to the blood group AB, you have both A and B antigens on the surface of your red blood cells and no A or B antibodies at all in your blood plasma.

Blood group 0



If you belong to the blood group 0 (null), you have neither A or B antigens on the surface of your red blood cells but you have both A and B antibodies in your blood plasma.

The following table shows the four ABO phenotypes (“blood groups”) present in the human population and the genotypes that give rise to them.

Blood Group	Antigens on RBCs	Antibodies in Serum	Genotypes
A	A	Anti-B	*AA* or *AO*
B	B	Anti-A	*BB* or *BO*
AB	A and B	Neither	*AB*
O	Neither	Anti-A and Anti-B	*OO*

If anti-A antibodies are mixed with blood cells that have the A antigen or mix anti-B antibodies with blood cells that have the B antigen, the results will be **agglutination** (or clumping of red blood cells). This reaction know can be used to type of blood. Take two drops of 'unknown' blood and place a drop of anti-A antibody solution on one blood drop and a drop of anti-B antibody solution on the other blood drop. Then, look closely to see if any clumping occurs. If clumping occurs in the drop of blood where anti-A antibodies are added, then A antigen is present (and, of course, if there is no clumping, then the A antigen is not present). If clumping occurs in the drop of blood where anti-B antibodies are added, then you B antigen is present (and, of course, if there is no clumping, then the B antigen is not present). Using this information, one can determine the blood type.

Drop of blood in which anti-A antibody was added	Drop of blood in which anti-B antibody was added	Blood type
Clumping	No clumping	A
No clumping	Clumping	B
Clumping	Clumping	AB
No clumping	No clumping	O

Many people also have a so-called Rh factor on the surface of red blood cell. This is also an antigen and those who have it are called Rh+. Those who do not have it are called Rh–. A person with Rh– blood does not have Rh antibodies naturally in the blood plasma (as one can have A or B antibodies, for instance). But a person with Rh– blood can develop Rh antibodies in the blood plasma if he or she receives blood from a person with Rh+ blood, whose Rh antigens can trigger the production of Rh antibodies. A person with Rh+ blood can receive blood from a person with Rh- blood without any problems.

B) Rh Factor Blood Grouping System

Rh antigens are transmembrane proteins with loops exposed at the surface of red blood cells. They appear to be used for the transport of carbon dioxide and/or ammonia across the plasma membrane. They are named for the rhesus monkey in which they were first discovered.

There are a number of Rh antigens. Red cells that are "Rh positive" express the one designated D. About 15% of the population have no RhD antigens and thus are "Rh negative".

The major importance of the Rh system for human health is to avoid the danger of RhD incompatibility between mother and fetus.

During birth, there is often a leakage of the baby's red blood cells into the mother's circulation. If the baby is Rh positive (having inherited the trait from its father) and the mother Rh–negative, these red cells will cause her to develop antibodies against the RhD antigen. The antibodies, usually of the IgG class, do not cause any problems for that child, but can cross the placenta and attack the red cells of a subsequent Rh^+ fetus. This destroys the red cells causing anemia and jaundice. The disease, called erythroblastosis fetalis or hemolytic disease of the newborn, may be so severe as to kill the fetus or even the newborn infant. It is an example of an antibody-mediated cytotoxicity disorder.

Blood group notation According to above blood grouping systems, you can belong to either of following 8 blood groups:

A Rh+	B Rh+	AB Rh+	0 Rh+
A Rh-	B Rh-	AB Rh-	0 Rh-

4.4 HEART

A) Introduction

The Heart is made up of a powerful muscle called myocardium. The myocardium is composed of cardiac muscle fibers that contracts and causes a wringing type of action.

The size of heart is a little larger than the size of our fist. The heart is located at about left-center of our chest. The heart are two separate pumps that continuously send blood throughout the body carrying nutrients, oxygen, and help in remove harmful wastes. The right side of the heart receives the blood low in oxygen. The left side of the heart receives the blood that has been oxygenated by the lungs. The blood is then pumped out into the aorta and to all parts of the body.

Right Atrium

The right atrium is larger than the left atrium but has thinner walls. The right atrium has two major veins that return blood to the heart from all parts of the body. Two major veins returning the blood to the heart are the superior vena cava and the inferior vena cava. These two veins are sometimes called the "Great Veins". The superior vena cava returns the deoxygenated blood from the upper part of the body and the inferior vena cava returns the deoxygenated blood from the lower part of the body. The right atrium also receives blood back from the heart muscle itself. After the blood is collected in the right atrium, it is pumped into the right ventricle through the tricuspid valve (three leaf valve).

Left Atrium

The left atrium receives the blood from four pulmonary veins. The blood received from the lungs has been oxygenated. The oxygenated blood that is collected in left atrium is then pumped into the left ventricle through the bicuspid valve.

Right Ventricle

The right ventricle receives the blood from the right atrium. When the heart contracts, the blood is forced out through the pulmonary semilunar valve into the pulmonary artery. The pulmonary semilunar valve is a three flap valve that stops the backflow of blood. The walls of the right ventricle are a little thicker than the right atrium.

Left Ventricle

The chamber of the left ventricle has walls whose thickness is three times that of right ventricle. This is important because the oxygenated blood that it receives from the left atrium has to be pumped throughout the body. The bicuspid valve closes and the blood is collected in the left ventricle. The closing of the bicuspid valve stops the backflow of blood. When the heart muscle contracts the blood is forced through the aortic semilunar valve, which has the same features as the pulmonary valve. The blood then passes through the aortic semilunar valve into the aorta.

Aorta

The aorta is the largest blood vessel in the body. The inner diameter of the aorta is about 1 inch. The aorta carries oxygenated blood to every other part of the body. It aorta receives its blood from the left ventricle.

Septum

The septum is a partition that separates the right and left sides of the heart. There are two separate regions of the septum. They are the interatrial septum that separates the atriums and the interventrial septum that separates the ventricles. The interventrial septum is only present in the fetal period and is open during this period. It closes at the time of birth. It is supposed to be closed all the time, but sometimes an opening is present at birth. This would be considered a congenital heart disease.

Superior Vena Cava

The importance of the superior vena cava is to return blood back to the right atrium from the upper part of the body. It is one of the largest veins in the body.

Inferior Vena Cava

The inferior vena cava is important for carrying the blood back to the right atrium from the lower part of the body.

Pulmonary Arteries

The pulmonary arteries carry the blood from the right ventricle to both of the lungs. There the blood is oxygenated and sent to the left atrium in the heart.

Pulmonary Veins

The pulmonary veins carry the oxygenated blood back to the left atrium in the heart.

The four heart valves include the following:

1. tricuspid valve: located between the right atrium and the right ventricle
2. pulmonary valve: located between the right ventricle and the pulmonary artery
3. mitral valve: located between the left atrium and the left ventricle
4. aortic valve: located between the left ventricle and the aorta

B) Mechanism of Heart Functioning

The heart is a powerful muscle slightly larger than our clenched fist. It works as a pump to send oxygen-rich blood through all parts of the body. Blood contains oxygen and nutrients that every cell in the body needs to survive. The oxygen-rich blood

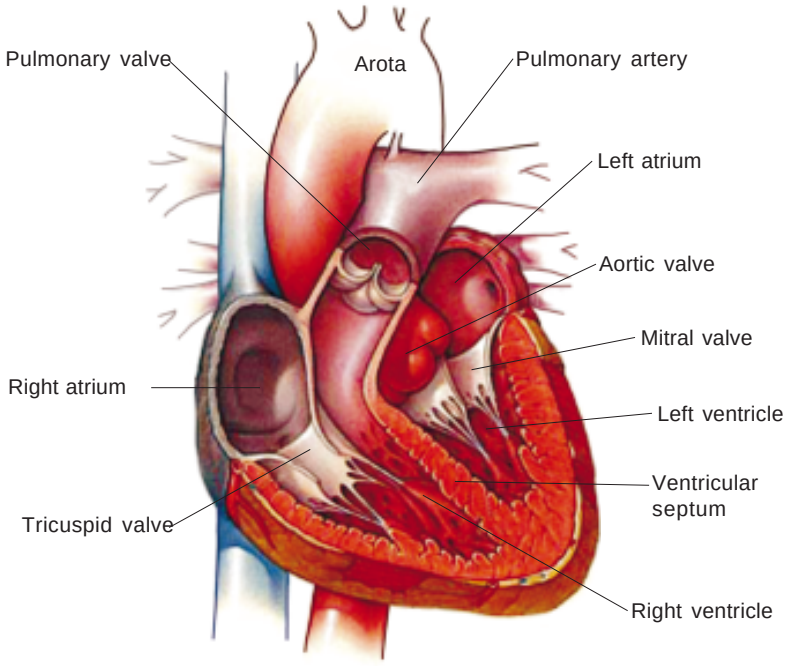


Fig. 4.1: Structure of heart.

travels throughout the arteries and vessels, nourishing the body so that it can function properly.

Heart beats at an average of 100,000 times per day. In that time, it pumps more than 4,300 gallons of blood throughout the entire body.

The heart is divided into two sides. Each side is divided again into two chambers, the atrium (upper chamber) and ventricle (lower chamber). Blood vessels (veins) carry blood to the heart from the rest of the body. This blood carries carbon dioxide and cellular waste products. The blood goes into the right atrium and then to the right ventricle, where it is then pumped to the lungs to dispose off wastes and receive a fresh oxygen supply. From the lungs, the blood returns to the heart. It returns to the left atrium and then to the left ventricle. The blood is then pumped out of the heart by the left ventricle into the aorta. The left ventricle is the chamber of the heart that is responsible for pumping blood to all parts of the body. The aorta sends this blood to small arteries, which carry the oxygen-rich blood to the rest of the body.

C) Cardiac Cycle

Cardiac cycle is the term referring to all or any of the events related to the flow of blood that occurs from the beginning of to heartbeat to the beginning of the next. The frequency of the cardiac cycle is the heart rate. Every single ‘beat’ of the heart

involves three major stages: **atrial systole**, **ventricular systole** and **complete cardiac diastole.** The term *diastole* is synonymous with relaxation of a muscle. Throughout the cardiac cycle, the blood pressure increases and decreases.

Atrial systole

Atrial systole is the contraction of the heart muscle (myocardia) of the left and right atria. Normally, both atria contract at the same time. The term systole is synonymous with contraction (movement or shortening) of a muscle. Electrical systole is the electrical activity that stimulates the myocardium of the chambers of the heart to make them contract. This is soon followed by mechanical systole, which is the mechanical contraction of the heart.

As the atria contract, the blood pressure in each atrium increases, forcing additional blood into the ventricles. The additional flow of blood is called atrial kick. Seventy per cent of the blood flows passively down to the ventricles, so the atria do not have to contract a great amount. Atrial kick is absent if there is loss of normal electrical conduction in the heart, such as during atrial fibrillation, atrial flutter, and complete heart block. Atrial kick is also different in character depending on the condition that the heart is in like stiff heart, which is found in patients with diastolic dysfunction.

Ventricular systole

The closing of the mitral and tricuspid valves (known together as the atrioventricular valves) at the beginning of ventricular systole cause the first part of the "lub-dub" sound made by the heart as it beats. Formally, this sound is known as the First Heart Tone. This first heart tone is created by the closure of mitral and tricuspid valve.

The second part of the "lub-dub" (the Second Heart Tone) is caused by the closure of the aortic and pulmonic valves at the end of ventricular systole. As the left ventricle empties, its pressure falls below the pressure in the aorta, and the aortic valve closes. Similarly, as the pressure in the right ventricle falls below the pressure in the pulmonary artery, the pulmonic valve closes. The aortic valve closes earlier than the pulmonic valve and they are audibly separated from each other in the second heart sound.

Complete cardiac diastole

Cardiac diastole is the period of time when the heart relaxes after contraction in preparation for refilling with circulating blood. Ventricular diastole is when the ventricles are relaxing, while atrial diastole is when the atria are relaxing. Together they are known as complete cardiac diastole.

During ventricular diastole, the pressure in the (left and right) ventricles drops from the peak that it reaches in systole. When the pressure in the left ventricle drops to

below the pressure in the left atrium, the mitral valve opens, and the left ventricle fills with blood that was accumulating in the left atrium. Likewise, when the pressure in the right ventricle drops below that in the right atrium, the tricuspid valve opens, and the right ventricle fills with blood that was accumulating in the right atrium.

Regulation of Cardiac Cycle

Cardiac muscle has automaticity, which means that it is self-exciting. This is in contrast with skeletal muscle, which requires either conscious or reflex nervous stimuli for excitation. The heart's rhythmic contractions occur spontaneously, although the rate of contraction can be changed by nervous or hormonal influences, exercise and emotions. For example, the sympathetic nerves to heart accelerate heart rate and the vagus nerve decelerates heart rate.

The rhythmic sequence of contractions is coordinated by the sinoatrial (SA) and atrioventricular (AV) nodes. The sinoatrial node, often known as the cardiac pacemaker, is located in the upper wall of the right atrium and is responsible for the wave of electrical stimulation that initiates atrial contraction by creating an action potential. Once the wave reaches the AV node, situated in the lower right atrium, it is delayed there before being conducted through the bundles of His and back up the Purkinje fibers, leading to a contraction of the ventricles. The delay at the AV node allows enough time for all of the blood in the atria to fill their respective ventricles. In the event of severe pathology, the AV node can also act as a pacemaker; this is usually not the case because their rate of spontaneous firing is considerably lower than that of the pacemaker cells in the SA node and hence is overridden.

Factors Affecting Cardiology

Some Clinical parameters of Heart functioninig

Blood pressure

Blood pressure is the pressure of the blood against the walls of the arteries. Blood pressure results from two forces. One is created by the heart as it pumps blood into the arteries and through the circulatory system. The other is the force of the arteries as they resist the blood flow. As the blood goes through the arterioles, the arterioles either contract or expand altering both the amount of blood flow and the resistance to blood flow. If the arterioles remain in a contracted form, they create high blood pressure. The heart must then pump harder because the arterioles are exerting a greater resistance to blood flow.

Blood pressure number

1. The higher (systolic) number represents the pressure while the heart contracts to pump blood to the body.
2. The lower (diastolic) number represents the pressure when the heart relaxes between beats.

The systolic pressure is always stated first. For example: 118/76 (118 over 76); systolic = 118, diastolic = 76.

Blood pressure below 120 over 80 mmHg (millimeters of mercury) is considered optimal for adults. A systolic pressure of 120 to 139 mmHg or a diastolic pressure of 80 to 89 mmHg is considered "prehypertension" and needs to be watched carefully. A blood pressure reading of 140 over 90 or higher is considered elevated (high).

It is highest in the arteries, low in the blood vessels and least in the veins.

Blood pressure is measured by an instrument called the **Sphygmomanometer.** The instrument records BP in how high it pushes the Hg level. It consists of an inflatable cuff fixed to a pressure guage or the manometer and a rubber pump.

1. The highest blood pressure in the arteries immediately after ventricular systole is recorded to be about 120 mm of Hg. It is called systolic blood pressure.
2. The lowest blood pressure in the arteries immediately after ventricular systole is recorded to be about 80 mm of Hg. It iscalled diastolic blood pressure.
3. BP decreases because of lowering of basal metabolic rate at rest.
4. **Hypertension:** BP increases above normal level i.e., 120/80 mm of Hg.
5. **Hypotension:** BP decreases below normal blood pressure.

Factors influencing BP

Blood Pressure does not remain constant but increases or decreases depending on various factors like age, sex, state of mind and state of the body.

AGE: In new born baby it is 40/80 mm of Hg and may go upto 40/150 mm of Hg in adults. In normal adults it is 70/90 mm of Hg.

SEX: Blood pressure of males is higher than females as blood in males is more viscous because of blood corpuscles.

STATE OF MIND: Emergency conditions like fear, anger, anxiety and even worry can increase BP.

STATE OF BODY: Physical exercise increases BP. Concentration of nicotine in blood, atherosclerosis and arteriosclerosis increases BP as it hardens, thickens and decreases

the lumen of the arteries. Obesity and nephritis increase BP and nervous and thyroid diversity disorders decrease BP.

Stroke volume

Stroke volume is the amount of blood pumped by the right/left ventricle of the heart in one contraction. The stroke volume is not all of the blood contained in the left ventricle. The heart does not pump all the blood out of the ventricle. Normally, only about two-thirds of the blood in the ventricle is put out with each beat. Blood actually pumped from the left ventricle is the stroke volume and it, together with the heart rate, determines the cardiac output.

Its value is obtained by subtracting end-systolic volume (ESV) from end-diastolic volume (EDV) for a given ventricle:

SV = EDV " ESV

In a healthy 70kg man, the left ventricular EDV is 120 ml and the corresponding ESV is 50 ml, giving a stroke volume of 70 ml.

Men, on average, have higher stroke volumes than women due to the larger size of their hearts. However, stroke volume depends on several factors such as heart size, contractility, duration of contraction, preload (end-diastolic volume), and afterload.

Cardiac output

Cardiac output (Q) is the volume of blood being pumped by the heart, in particular by a ventricle in a minute. This is measured in dm^3 min^{-1} (1 dm^3 equals 1000cm^3 or 1 litre).

Normal output

Cardiac output is equal to the stroke volume (SV) multiplied by the heart rate (HR). SV is the volume of blood pumped per beat and the HR is the number of beats per minute. Therefore, if there are 70 beats per minute, and 70 ml blood is ejected with each beat, (SV), the cardiac output (Q) is 4900 ml/minute. This value is typical for an average adult at rest, although Q may reach up to 31.97865 litres/minute during extreme exercise by elite athletes.

Clinical Use

The function of the heart is to transport the blood to deliver oxygen, nutrients and chemicals to the cells of the body to ensure their survival and proper functioning and to remove the cellular wastes. Q indicates how well the heart is performing this function. Q is regulated principally by the demand of oxygen by the cells of the body. If the cells

are working hard with a high metabolic oxygen demand, then the Q is raised to increase the supply of oxygen to the cells, while at rest when the cellular demand is low, the Q is said to be baseline. Q is regulated not only by the heart as it pumps, but also by the function of the vessels of the body as they actively relax and contract thereby increasing and decreasing the resistance to flow.

Stroke Volume (SV) = EDV – ESV

Ejection Fraction (EF) = (SV / EDV) × 100%

Cardiac Output (Q) = SV × HR

Pulse

In medicine, a person's **pulse** is the throbbing of their arteries as an effect of the heart beat. It can be felt in any place that allows for an artery to be compressed against a bone, such as at the neck, at the wrist, behind the knee, on the inside of the elbow (brachial artery), and near the ankle joint. The pulse rate can also be measured by measuring the heart beats directly (the apical pulse).

Pressure waves move the artery walls, which are pliable; these waves are not caused by the forward movement of the blood. When the heart contracts, blood is ejected into the aorta and the aorta stretches. *Pulse* is also used, although incorrectly, to denote the frequency of the heart beat, usually measured in beats per minute. In most people, the pulse is an accurate measure of heart rate. The pulse is too irregular and the heart rate can be (much) higher than the pulse rate. A normal pulse rate for a healthy adult, while resting, can range from 60 to 100 beats per minute (BPM), although well conditioned athletes may have a healthy pulse rate lower than 60 BPM.

Electro Cardio Gram (ECG)

An electrocardiogram (ECG or EKG, abbreviated from the German Elektrokardiogramm) is a graphic produced by an electrocardiograph, which records the electrical activity of the heart over time. Its name is made of different parts: electro, because it is related to electronics, cardio, Greek for heart, gram, a Greek root meaning "to write". Electrical waves cause the heart muscle to pump. These waves pass through the body and can be measured at electrodes (electrical contacts) attached to the skin. Electrodes on different sides of the heart measure the activity of different parts of the heart muscle. An ECG displays the voltage between pairs of these electrodes, and the muscle activity that they measure, from different directions. This display indicates the overall rhythm of the heart, and weaknesses in different parts of the heart muscle.

A graphical record of the electrical changes occurring during a heartbeat. A typical ECG is composed of a P wave, representing depolarization of the atria; the P-R interval,

indicating the delay in conduction at the atrioventricular node; the QRS complex, produced during ventricular depolarization and contraction; and the T wave and ST segment, corresponding to ventricular repolarization. When read and interpreted by a highly skilled and experienced physician, an ECG is probably the most useful record of heart function. It can reveal the cause of irregular heart beats and damage to the heart muscle. It can also show enlargement of heart chambers, mineral imbalances in the blood, and whether someone has had or is having a heart attack. ECGs are recorded while the subject is resting or exercising. An exercise ECG, also called a stress test, can provide information on cardiorespiratory fitness and how the heart responds to strenuous exercise. It often forms part of the medical screening process of potential exercisers.

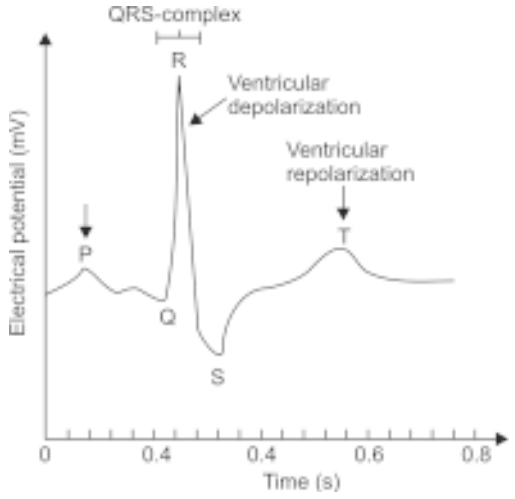


Fig. 4.2: Electrocardiogram.

4.5 BLOOD VESSELS

The blood vessels are part of the cardiovascular system and function to transport blood throughout the body. The most important vessels in the system are the capillaries, the microscopic vessels which enable the actual exchange of water and chemicals between the blood and the tissues, while the conduit vessels, arteries and veins carry blood away from the heart and through the capillaries or back towards the heart, respectively.

Structural Anatomy of Blood Vessel

All blood vessels have the same basic structure. There are three layers, from inside to outside:

1. ***Tunica intima*** (the thinnest layer): a single layer of simple squamous endothelial cells glued by a polysaccharide intercellular matix, surrounded by a thin layer of

subendothelial connective tissue interlaced with a number of circularly arranged elastic bands called the *internal elastic lamina*.

2. ***Tunica media*** (the thickest layer): circularly arranged elastic fiber, connective tissue, polysaccharide substances. The second and third layers are separated by another thick elastic band called external elastic lamina. The tunica media may (especially in arteries) be rich in vascular smooth muscle, which controls the caliber of the vessel.
3. ***Tunica adventitia*****:** entirely made of connective tissue. It also contains nerves that supply the muscular layer, as well as nutrient capillaries (vasa vasorum) in the larger blood vessels.

Capillaries consist of little more than a layer of endothelium and occasional connective tissue.

Arteries

Arteries are muscular blood vessels that carry blood away from the heart. All arteries, with the exception of the pulmonary and umbilical arteries, carry oxygenated blood. The circulatory system is extremely important for sustaining life. Its proper functioning is responsible for the delivery of oxygen and nutrients to all cells, as well as the removal of carbon dioxide and waste products, maintenance of optimum pH, and the mobility of the elements, proteins and cells of the immune system.

There are several types of arteries in the body.

Pulmonary arteries

The pulmonary arteries carry deoxygenated blood that has just returned from the body to the lungs, where carbon dioxide is exchanged for oxygen.

Systemic arteries

Systemic arteries can be subdivided into two types, muscular and elastic, according to the relative compositions of elastic and muscle tissue in their tunica media as well as their size and the make-up of the internal and external elastic lamina. The larger arteries (>1cm) diameter are generally elastic and the smaller ones (0.1–10 mm) tend to be muscular. Systemic arteries deliver blood to the arterioles, and then to the capillaries, where nutrients and gases are exchanged.

The Aorta

The aorta is the root systemic artery. It receives blood directly from the left ventricle of the heart via the aortic valve. As the aorta branches and these arteries branch in

turn, they become successively smaller in diameter, down to the arteriole. The arterioles supply capillaries, which in turn empty into venules.

Arterioles

Arterioles, the smallest of the true arteries, help regulate blood pressure by the variable contraction of the smooth muscle of their walls, and deliver blood to the capillaries.

Veins

In the circulatory system, vein is a blood vessel that carries blood towards the heart. The majority of veins in the body carry low-oxygen blood from the tissues back to the heart; the exceptions being the pulmonary and umbilical veins which carry oxygenated blood.

Functions of Vein

Veins serve to return blood from organs to the heart. In systemic circulation, oxygenated blood is pumped by the left ventricle through the arteries to the muscles and organs of the body, where its nutrients and gases are exchanged at capillaries, entering the veins filled with cellular waste and carbon dioxide. The de-oxygenated blood is taken by veins to the right atrium of the heart, which transfers the blood to the right ventricle, where it is then pumped through the pulmonary arteries to the lungs. In pulmonary circulation the pulmonary veins return oxygenated blood from the lungs to the left atrium, which empties into the left ventricle, completing the cycle of blood circulation.

The arteries are perceived as carrying oxygenated blood to the tissues, while veins carry deoxygenated blood back to the heart. This is true of the systemic circulation, by far the larger of the two circuits of blood in the body, which transports oxygen from the heart to the tissues of the body. However, in pulmonary circulation the arteries carry deoxygenated blood from the heart to the lungs and veins return blood from the lungs to the heart. The difference between veins and arteries is their direction of flow (out of the heart by arteries, returning to the heart for veins), not their oxygen content. In addition, deoxygenated blood that is carried from the tissues back to the heart for reoxygenation in systemic circulation still carries some oxygen, though it is considerably less than that carried by the systemic arteries or pulmonary veins.

Capillaries

Sinusoids

Sinusoids are tiny vessels found in the liver, spleen, and bone marrow. While most other tissues of the body have capillaries that transport blood from the arteries to the veins, these tissues have sinusoids.

Similar to capillaries, sinusoids are composed of endothelium. Oxygen, carbon dioxide, nutrients, proteins, and wastes are exchanged through the thin walls of the sinusoids.

4.6 LYMPHATIC SYSTEM

An often overlooked part of the circulatory system is the lymphatic system. As blood passes through the capillaries, some of the fluid diffuses into the surrounding tissues. One function of the lymphatic system is to collect and recycle this fluid (called lymph). Lymph passes from capillaries to lymph vessels and flows through lymph nodes that are located along the course of these vessels. Cells of the lymph nodes phagocytize, or ingest, impurities such as bacteria, old red blood cells, and toxic and cellular waste. Finally, lymph flows into the thoracic duct, a large vessel that runs parallel to the spinal column, or into the right lymphatic duct, both of which transport the lymph back into veins of the shoulder areas where it mixes with blood and is returned to the heart. All lymph vessels contain one-way valves, like the veins, to prevent backflow.

The tissues of the lymphatic system include the spleen. The spleen serves as a reservoir for blood, releasing additional blood into the circulatory system as needed. It is also involved in destruction of old cells and other substances by phagocytosis. The lymphatic system is also responsible for collecting nutrients that the digestive system has extracted from our foods, and is a very important part of the immune system.

The lymphatic system consists of organs, ducts, and nodes. It transports a watery clear fluid called lymph. This fluid distributes immune cells and other factors throughout the body. It also interacts with the blood circulatory system to drain fluid from cells and tissues. The lymphatic system contains immune cells called lymphocytes, which protect the body against antigens (viruses, bacteria, etc.) that invade the body.

Main functions of lymphatic system:

- To collect and return interstitial fluid, including plasma protein to the blood, and thus help maintain fluid balance.
- To defend the body against diseases by producing lymphocytes.
- To absorb lipids from the intestine and transport them to the blood.

Structure of Lymphatic Vessels

Lymphatic vessels resemble veins in structure with certain exceptions. (1) Lymphatics have thinner walls. (2) Lymphatics contain more valves. (3) Lymphatics contain lymph nodes located at certain intervals along their course.

Functions of Lymphatic Vessels

1. Lymphatics play a critical role in homeostasis.
2. The high degree of capillary permeability permits large molecular weight substances, which cannot be absorbed by the blood capillary, to be removed from the interstitial spaces.
3. Proteins that accumulate in the interstitial spaces can return to the blood only via lymphatics. This is of great clinical importance.
4. If anything blocks lymphatic return, blood protein and blood osmotic pressure fall below normal. Thre will be fluid imbalance, thus resulting in death.
5. Lacteals (lymphatics in the villi of the small intestine) serve an important function in the absorption of fats and other nutrients.
6. The lymph found in lacteals after digestion contains 1-2% fat and is called **chyle**.

Structure of Lymph Nodes

Lymph nodes are oval-shaped or bean-shaped structures. Some are as small as a pinhead and others as large as a lima bean. Each lymph node is enclosed by a fibrous capsule. Note that lymph moves into a node via several different lymphatic vessels and emerges by one or two efferent vessel. Think of a lymph node as a biological filter placed in the channel of several afferent lymph vessels. Once the lymph enters the node, it "percolates" slowly through the spaces known as **sinuses** before draining into a single efferent draining vessel. One-way valves in both the afferent and efferent vessels keep lymph flowing in one direction.

Function of Lymph Nodes

Nodes act as filters, with an internal honeycomb of reticular connective tissue filled with lymphocytes that collect and destroy bacteria and viruses. When the body is fighting an infection, lymphocytes multiply rapidly and produce a characteristic swelling of the lymph nodes. When the lymphatic fluid is in the tissues before going into a lymph node, it is called interstitial fluid.

Lymph Organs

Spleen

The spleen is a lymphatic organ interposed in the blood stream. The surface projection of the longitudinal axis of the spleen is the tenth rib. It is concealed anteriorly by the greater curvature of the stomach and the left colic (splenic) flexure. Its weight varies from 50 to 250g. The **spleen** is an organ located in the abdomen of the human body,

where it functions in the destruction of old red blood cells and holds a reservoir of blood. It is regarded as one of the centers of activity of the reticuloendothelial system (part of the immune system). Until recently, the purpose of the spleen was not known. It is increasingly recognized that its absence leads to a predisposition to certain infections.

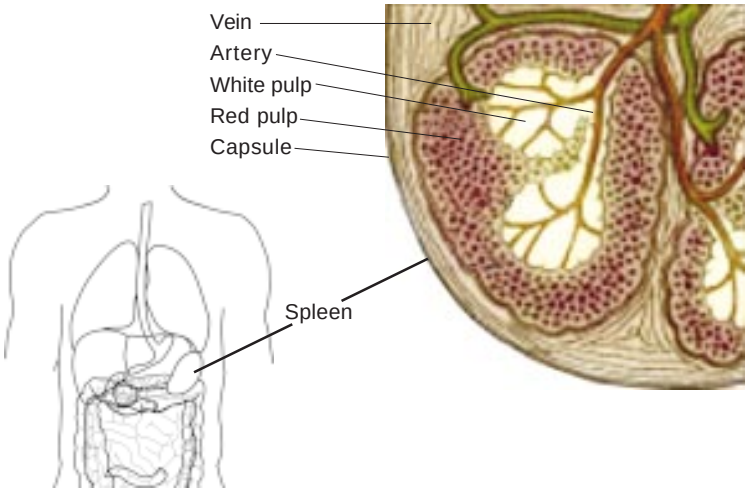


Fig. 4.3: Structure of Spleen.

Functions of spleen

1. Reticuloendothelial tissue—concerned with phagocytosis of erythrocytes and cell debris from the blood stream. This same tissue may produce foci of haemopoiesis when RBC's are needed.
2. Venous sinusoids along with the power of the spleen to contract, provides a method for expelling the contained blood to meet increased circulatory demands in certain animals.
3. White pulp provides lymphocytes and a source of plasma cells and hence antibodies for the cellular and humoral specific immune defenses.

Thymus

The thymus is an organ located in the upper anterior portion of the chest cavity just behind the sternum. Hormones produced by this organ stimulate the production of certain infection-fighting cells. It is of central importance in the maturation of T cells.The thymus of a lamb or calf is eaten, with the pancreas, as the sweetbreads.

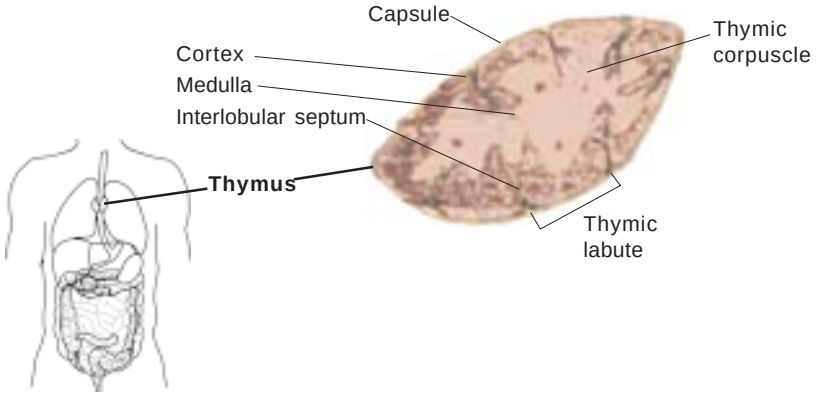


Fig. 4.4: Structure of thymus.

Structure of thymus

The cortical portion is mainly composed of lymphoid cells, supported by a network of finely-branched epithelial reticular cells, which is continuous with a similar network in the medullary portion. This network forms an adventitia to the blood vessels.The cortex is the location of the earliest events in thymocyte development, where T cell receptor gene rearrangement and positive selection takes place.

Functions

Lymphocytes originate from haemocytoblasts (stem cells) in red bone marrow. Those that enter the thymus mature and develop into activated T-lymphocytes i.e., able to respond to antigens encountered elsewhere in the body. They then divide into two groups:

1. Those that enter the blood, some of which remain in circulation and some lodge in other lymphoid tissue.
2. Those that remain in the thymus gland and are the source of future generations of T-lymphocytes.

The maturation of the thymus and other lymphoid tissue is stimulated by thymosin, a hormone secreted by the epithelial cells that form the framework of the thymus gland. Involution of the gland begins in adolescence and, with increasing age, the effectiveness of T- lymphocyte response to antigens declines.

4.7 IMMUNE SYSTEM

An immune system is a collection of mechanisms within an organism that protects against disease by identifying and killing pathogens and tumor cells. It detects a wide variety of agents, from viruses to parasitic worms, and needs to distinguish them

from the organism's own healthy cells and tissues in order to function properly. Detection is complicated as pathogens adapt and evolve new ways to successfully infect the host organism. To survive this challenge, several mechanisms have evolved that recognize and neutralize pathogens. Even simple unicellular organisms such as bacteria possess enzyme systems that protect against viral infections. Other basic immune mechanisms evolved in ancient eukaryotes and remain in their modern descendants, such as plants, fish, reptiles, and insects.

Immunity is a state of having sufficient biological defenses to avoid infection, disease, or other unwanted biological invasion, and is related to the functions of the immune system.

Specific Immunity

Sometimes known as acquired immunity. It forms the body's third line of defence. Specific Immunity has following features:

Specificity: Responds to specific antigens.

Diversity: 10^8 (Ten million) different antibodies self / Non-Self Recognition.

Memory: recognises previously encountered antigens and reacts faster and more effectively to subsequent exposures. e.g., chicken pox.

Specific Immune Response is divided into two categories: Cellmediated immunity and humoral immunity.

Cell-Mediated immunity relies upon T-lymphocyte cells attacking the invading organism. These are called T-cells because they are formed in thymus.

Humoral immunity is antibody dependent and relies upon body fluids, especially the lymph and the blood plasma to spread antibodies around the body. The antibodies are produced by B-lymphocytes, named after a lymphatic organ found in birds called the bursa where these cells are processed. No equivalent organ is known in man and it is thought that the processing of B-cells occurs in the bone marrow and the foetal liver.

Non Specific Immunity

Microorganisms that successfully enter an organism will encounter the cells and mechanisms of the innate immune system. The innate response is usually triggered when microbes are identified by pattern recognition receptors, which recognize components that are conserved among broad groups of microorganisms. Innate immune defenses are non-specific, i.e., these systems respond to pathogens in a generic way. This system does not confer long-lasting immunity against a pathogen. The innate immune system is the dominant system of host defense in most organisms.

The characteristics of the innate immune response include the following:

1. Responses are broad-spectrum (non-specific)
2. There is no memory or lasting protective immunity
3. There is a limited repertoire of recognition molecules
4. The responses are phylogenetically ancient.

Cell Mediated Immunity

Cell-mediated immunity is an immune response that does not involve antibodies but rather involves the activation of macrophages, natural killer cells (NK), antigen-specific cytotoxic T-lymphocytes, and the release of various cytokines in response to an antigen.

Cellular immunity protects the body by:

1. activating antigen-specific cytotoxic T-lymphocytes that are able to induce apoptosis in body cells displaying epitopes of foreign antigen on their surface, such as virus-infected cells, cells with intracellular bacteria, and cancer cells displaying tumor antigens;
2. activating macrophages and natural killer cells, thus enabling them to destroy intracellular pathogens; and
3. stimulating cells to secrete a variety of cytokines that influence the function of other cells involved in adaptive immune responses and innate immune responses.

Cell-mediated immunity is directed primarily at microbes that survive in phagocytes and microbes that infect non-phagocytic cells. It is most effective in removing virus-infected cells, but also participates in defending against fungi, protozoans, cancers, and intracellular bacteria. It also plays a major role in transplant rejection.

T cell Types

T cells contribute to the immune defenses in two major ways. Some regulate the complex workings of the immune system, while others are cytotoxic and directly contact infected cells and destroy them. Chief among the **regulatory T cells** are "helper/inducer" T cells. They are needed to activate many immune cells, including B cells and other T cells. Another subset of regulatory T cells acts to turn off or suppress immune cells.

Cytotoxic T cells help rid the body of cells that have been infected by viruses as well as cells that have been transformed by cancer. They are also responsible for the rejection of tissue and organ grafts.

Antibody mediated immunity

Stages in this process are:

1. antigen detection
2. activation of helper T cells
3. antibody production by B cells

Each stage is directed by a specific cell type.

Macrophages

Macrophages are white blood cells that continually search for foreign (nonself) antigenic molecules, viruses, or microbes. When found, the macrophages engulf and destroy them. Small fragments of the antigen are displayed on the outer surface of the macrophage plasma membrane.

Helper T cells

Helper T cells are macrophages that become activated when they encounter the antigens now displayed on the macrophage surface. Activated T cells identify and activate B cells.

B cells

B cells divide, forming plasma cells and B memory cells. Plasma cells make and release between 2000 and 20,000 antibody molecules per second into the blood for the next four or five days. B memory cells live for months or years, and are part of the immune memory system.

Antibodies

Antibodies bind to specific antigens in a lock-and-key fashion, forming an antigen-antibody complex. Antibodies are a type of protein molecule known as immunoglobulins. There are five classes of immunoglobulins: IgG, IgA, IgD, IgE, and IgM. A unique antigenic determinant recognizes and binds to a site on the antigen, leading to the destruction of the antigen in several ways. The ends of the Y are the antigen-combining site that is different for each antigen.

Helper T cells activate B cells that produce antibodies. Supressor T cells slow down and stop the immune response of B and T cells, serving as an off switch for the immune system. Cytotoxic (or killer) T cells destroy the body cells infected with virus or bacteria. Memory T cells remain in the body awaiting the reintroduction of the antigen.

A cell infected with a virus displays viral antigens on its plasma membrane. Killer T cells recognize the viral antigens and attach to that cell's plasma membrane. The

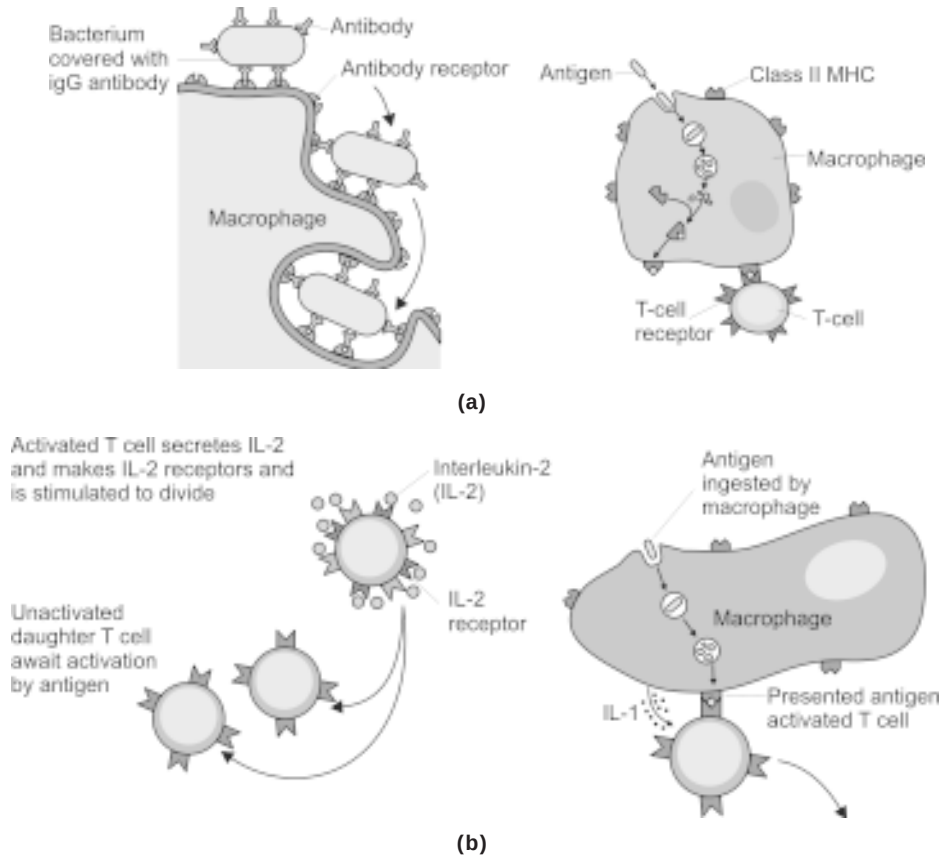


Fig. 4.5: (a) Helper T cells (b) B cells.

T cells secrete proteins that punch holes in the infected cell's plasma membrane. The infected cell's cytoplasm leaks out, the cell dies, and is removed by phagocytes. Killer T cells may also bind to the cells of transplanted organs.

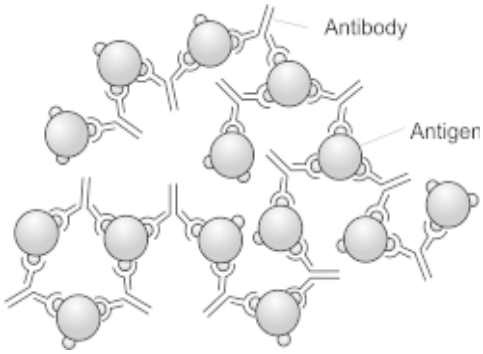


Fig. 4.6: Antibodies binding to antigen in lock and key fashion.

CHAPTER 5

Endocrine System

"Hormones are chemi-messengers
Effective agents of info-exchangers
Secretions are the inbuilt managers"

5.1 INTRODUCTION

All physiological activities are regulated by two major systems in the body. One is nervous system and the other is the endocrine system. These two systems interact with one another and regulate the body functions.

Endocrine system functions by secreting some chemical substances called chemical messengers or chemical mediators. These are commonly referred as ductless glands because the hormone is then carried in the bloodstream to target tissues and organs that may be quite distant, where they influence cellular growth and metabolism.

In vertebrates, endocrine system consists of a number of distinct glands and some tissues in other organs. Although the hypothalamus is classified as a part of the brain and not as an endocrine gland, it controls the pituitary gland and has an indirect effect on many others.

The level of a hormone in the blood is variable and self regulating within its normal range. A hormone is released in response to a specific stimulus and action reverses or negates the stimulus through a negative feedback mechanism. The positive feedback mechanism is the amplification of the stimulus and increases the release of hormone until a particular process is complete and stimulus ceases.

Hormones can be chemically classified into four groups:

1. Amino acid-derived hormones are modified amino acids.
2. Polypeptide and protein hormones are chains of amino acids of less than or more than about 100 amino acids, respectively. Some protein hormones are actually glycoproteins, containing glucose or other carbohydrate groups.
3. Steroid hormones are lipids that are synthesized from cholesterol. Steroids are characterized by four interlocking carbohydrate rings.
4. Eicosanoids are lipids that are synthesized from the fatty acid chains of phospholipids found in plasma membrane.

Mechanisms of Hormone Action

Hormones circulating in the blood diffuse into the interstitial fluids surrounding the cell. Cells with specific receptors for a hormone respond with an action that is appropriate for the cell. Because of the specificity of hormone and target cell, the effects produced by a single hormone may vary among different kinds of target cells.

Hormones activate target cells by one of two methods, depending upon the chemical nature of the hormone:

Lipid-soluble hormones (steroid hormones and hormones of the thyroid gland): These diffuse through the cell membranes of target cells. The lipid-soluble hormone then binds to a receptor protein which in turn, activates a DNA segment that turns on specific genes. The proteins produced as result of the transcription of the genes and subsequent translation of mRNA act as enzymes that regulate specific physiological cell activity.

Water-soluble hormones (polypeptide, protein, and most amino acid hormones): These bind to a receptor protein on the plasma membrane of the cell. The receptor protein, in turn, stimulates the production of one of the following second messengers:

Cyclic AMP (cAMP) is produced when the receptor protein activates another membrane-bound protein called G protein. The G protein activates adenylate cyclase, the enzyme that catalyzes the production of cAMP from ATP. Cyclic AMP then triggers an enzyme that generates specific cellular changes.

Inositol triphosphate (IP3) is produced from membrane phospholipids. IP_3, in turn, triggers the release of Ca^{2+} from the endoplasmic reticulum, which then activates enzymes that generate cellular changes.

5.2 STRUCTURE AND CHARACTERISTICS OF ENDOCRINE SYSTEM

The endocrine system is a complex collection of hormone-producing glands that control basic body functions such as metabolism, growth and sexual development. The endocrine glands consist of pituitary pineal thyroid and parathyroids adrenals pancreas thymus testes (male); and ovaries (female).

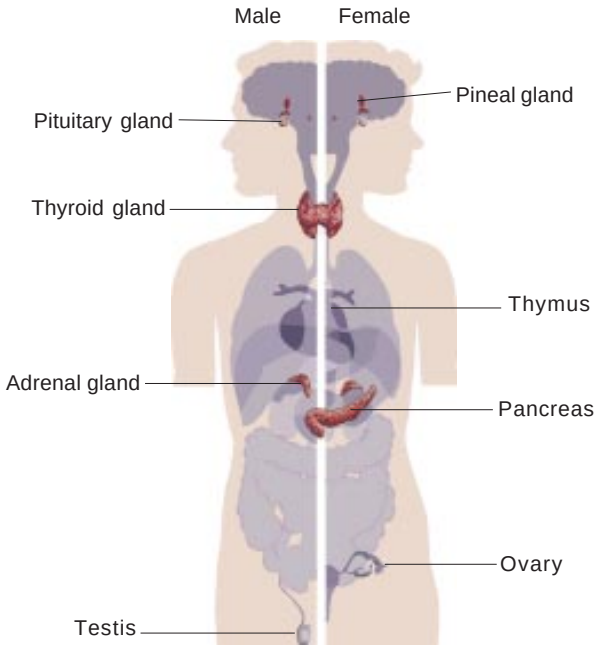


Fig. 5.1: Major endocrine glands in male and female.

Hormones are the chemical signaling molecules produced by the endocrine glands and secreted directly into the bloodstream. They travel through the blood to distant tissues and organs, where they can bind to specific cell sites called receptors. By binding to receptors, hormones trigger various responses in the tissues containing the receptors.

A) Pituitary Gland

The pituitary gland or hypophysis is a small gland, about 1 centimeter in diameter or the size of a pea. It is nearly surrounded by bone as it rests in the sella turcica, a depression in the sphenoid bone. The gland is connected to the hypothalamus of the brain by a slender stalk called the infundibulum.

There are two distinct regions in the gland: the anterior lobe (adenohypophysis) and the posterior lobe (neurohypophysis). The activity of the adenohypophysis is controlled

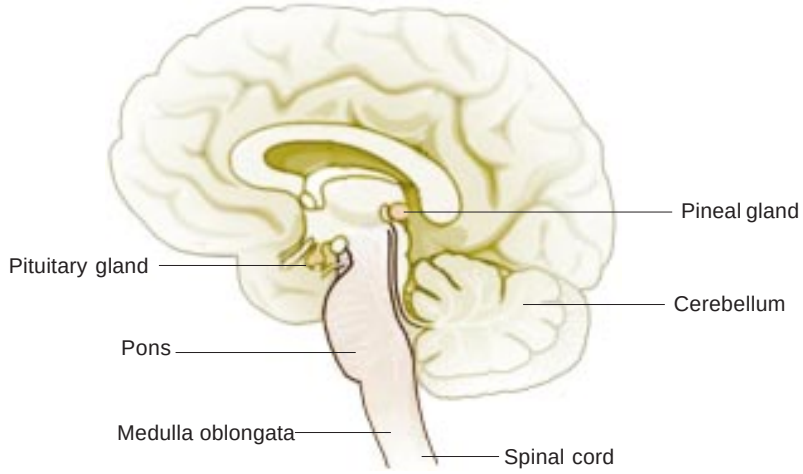


Fig. 5.2: Pituitary and pineal gland

by releasing hormones from the hypothalamus. The neurohypophysis is controlled by nerve stimulation.

Hormones of the anterior lobe (Adenohypophysis)

Growth hormone is a protein that stimulates the growth of bones, muscles, and other organs by promoting protein synthesis. This hormone drastically affects the appearance of an individual because it influences height. If there is too little growth hormone in a child, that person may become a pituitary dwarf of normal proportions but small stature. An excess of the hormone in a child results in an exaggerated bone growth, and the individual becomes exceptionally tall or a giant.

Thyroid-stimulating hormone, or thyrotropin, causes the glandular cells of the thyroid to secrete thyroid hormone. When there is a hypersecretion of thyroid-stimulating hormone, the thyroid gland enlarges and secretes too much thyroid hormone.

Adrenocorticotropic hormone (ACTH) reacts with receptor sites in the cortex of the adrenal gland to stimulate the secretion of cortical hormones, particularly cortisol.

Gonadotropic hormones react with receptor sites in the gonads, or ovaries and testes, to regulate the development, growth, and function of these organs.

Prolactin hormone promotes the development of glandular tissue in the female breast during pregnancy and stimulates milk production after the birth of the infant.

Hormones of the posterior lobe (Neurohypophysis)

Antidiuretic hormone promotes the reabsorption of water by the kidney tubules, with the result that less water is lost as urine. This mechanism conserves water for the body. Insufficient amounts of antidiuretic hormone cause excessive water loss in the urine.

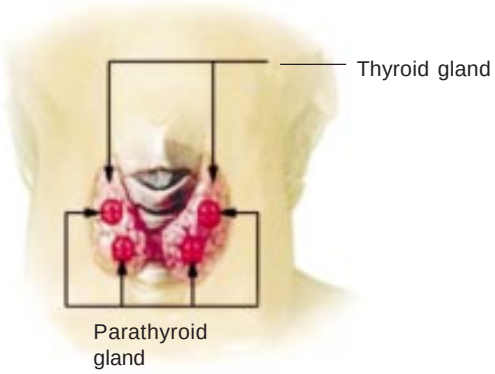
Oxytocin causes contraction of the smooth muscle in the wall of the uterus. It also stimulates the ejection of milk from the lactating breast.

B) Pineal Gland

The pineal gland, also called pineal body or epiphysis cerebri, is a small cone-shaped structure that extends posteriorly from the third ventricle of the brain. The pineal gland consists of portions of neurons, neuroglial cells, and specialized secretory cells called pinealocytes. The pinealocytes synthesize the hormone melatonin and secrete it directly into the cerebrospinal fluid, which takes it into the blood. Melatonin affects reproductive development and daily physiologic cycles.

C) Thyroid Gland

The thyroid gland is a vascular organ that is located in the neck. It consists of two lobes, one on each side of the trachea, just below the larynx or voice box. The two lobes are connected by a narrow band of tissue called the isthmus. Internally, the gland consists of follicles, which produce thyroxine and triiodothyronine hormones. These hormones contain iodine.



Fig, 5.3: Thyroid and parathyroid glands.

About 95 percent of the active thyroid hormone is thyroxine, and most of the remaining 5 percent is triiodothyronine. Both of these require iodine for their synthesis. Thyroid hormone secretion is regulated by a negative feedback mechanism that involves the amount of circulating hormone, hypothalamus, and adenohypophysis.

If there is an iodine deficiency, the thyroid cannot make sufficient hormone. This stimulates the anterior pituitary to secrete thyroid-stimulating hormone, which causes the thyroid gland to increase in size in a vain attempt to produce more hormones. But it cannot produce more hormones because it does not have the necessary raw material, iodine. This type of thyroid enlargement is called simple goiter or iodine deficiency goiter.

Calcitonin is secreted by the parafollicular cells of the thyroid gland. This hormone opposes the action of the parathyroid glands by reducing the calcium level in the blood. If blood calcium becomes too high, calcitonin is secreted until calcium ion levels decrease to normal.

D) Parathyroid Gland

Four small masses of epithelial tissue are embedded in the connective tissue capsule on the posterior surface of the thyroid glands. These are parathyroid glands, and they secrete parathyroid hormone or parathormone. Parathyroid hormone is the most important regulator of blood calcium levels. The hormone is secreted in response to low blood calcium levels, and its effect is to increase those levels.

Hypoparathyroidism, or insufficient secretion of parathyroid hormone, leads to increased nerve excitability. The low blood calcium levels trigger spontaneous and continuous nerve impulses, which then stimulate muscle contraction.

E) Adrenal Gland

The adrenal, or suprarenal gland is paired with one gland located near the upper portion of each kidney. Each gland is divided into an outer cortex and an inner medulla. The cortex and medulla of the adrenal gland, like the anterior and posterior lobes of the pituitary, develop from different embryonic tissues and secrete different hormones. The adrenal cortex is essential to life, but the medulla may be removed with no life-threatening effects.

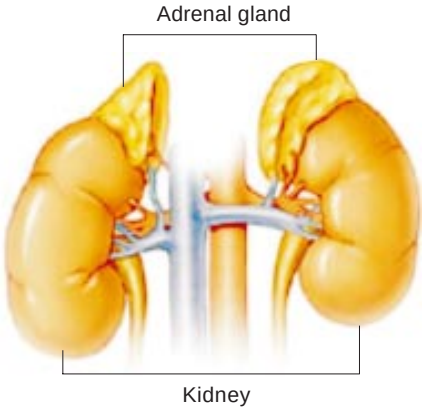


Fig. 5.4: Adrenal Gland.

The hypothalamus of the brain influences both portions of the adrenal gland but by different mechanisms. The adrenal cortex is regulated by negative feedback involving the hypothalamus and adrenocorticotropic hormone (ACTH); the medulla is regulated by nerve impulses from the hypothalamus.

Hormones of the Adrenal Cortex

The adrenal cortex consists of three different regions, with each region producing a different group or type of hormones. Chemically, all the cortical hormones are steroid.

Mineralocorticoids are secreted by the outermost region of the adrenal cortex. The principal mineralocorticoid is **aldosterone**, which helps maintain blood pressure and the balance of water and salt in the body by helping the kidney retain sodium and excrete potassium. Glucocorticoids are secreted by the middle region of the adrenal cortex. The principal glucocorticoid is **cortisol**, which helps to,

- maintain blood pressure and cardiovascular function;
- slow the immune system's inflammatory response;
- balance the effects of insulin in breaking down sugar for energy;
- regulate the metabolism of proteins, carbohydrates, and fats; and
- maintain proper arousal and sense of well-being;

The third group of steroids secreted by the adrenal cortex is the gonadocorticoids, or sex hormones. These are secreted by the innermost region. Male hormones, androgens, and female hormones, estrogens, are secreted in minimal amounts in both sexes by the adrenal cortex, but their effect is usually masked by the hormones from the testes and ovaries. In females, the masculinization effect of androgen secretion may become evident after menopause, when estrogen levels from the ovaries decrease.

Hormones of the Adrenal Medulla

The adrenal medulla develops from neural tissue and secretes two hormones, epinephrine and norepinephrine. These two hormones are secreted in response to stimulation by sympathetic nerve, particularly during stressful situations. A lack of hormones from the adrenal medulla produces no significant effects. Hypersecretion, usually from a tumor, causes prolonged or continual sympathetic responses.

F) Pancreas

The pancreas is a long, soft organ that lies transversely along the posterior abdominal wall, posterior to the stomach, and extends from the region of the duodenum to the spleen. This gland has an exocrine portion that secretes digestive enzymes that are carried through a duct to the duodenum. The endocrine portion consists of the pancreatic islets, which secrete glucagons and insulin.

Alpha cells in the pancreatic islets secrete the hormone glucagons in response to a low concentration of glucose in the blood. Beta cells in the pancreatic islets secrete the hormone insulin in response to a high concentration of glucose in the blood.

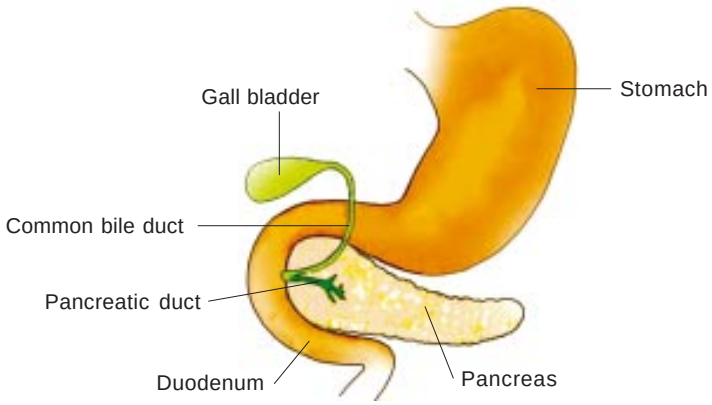


Fig. 5.5:

G) Thymus

Thymus is a bilobed organ located in the mediastinum between the sternum and aorta.An enveloping layer of connective tissue holds the two lobes closely together,but a connective tissue capsule encloses each lobe separately .

Thymosin, produced by the thymus gland, plays an important role in the development of immune system.

H) Testes

Male sex hormones, as a group, are called androgens. The principal androgen is testosterone, which is secreted by the testes. A small amount is also produced by the adrenal cortex. Production of testosterone begins during fetal development, continues

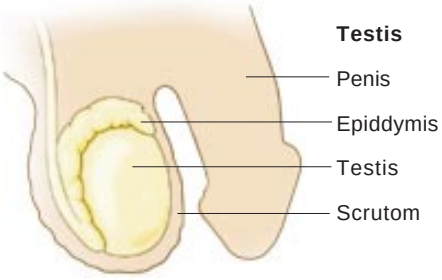


Fig. 5.6: Testes.

for a short time after birth, nearly ceases during childhood, and then resumes at puberty. This steroid hormone is responsible for:

- the growth and development of the male reproductive structures;
- increased skeletal and muscular growth;
- enlargement of the larynx accompanied by voice changes;
- growth and distribution of body hair; and
- increased male sexual drive.

Testosterone secretion is regulated by a negative feedback system that involves releasing hormones from the hypothalamus and gonadotropins from the anterior pituitary.

I) Ovaries

Two groups of female sex hormones are produced in the ovaries, the estrogens and progesterone. These steroid hormones contribute to the development and function of the female reproductive organs and sex characteristics. At the onset of puberty, estrogen promotes the development of the breasts, distribution of fat evidenced in the hips, legs, breast, and maturation of reproductive organs such as the uterus and vagina.

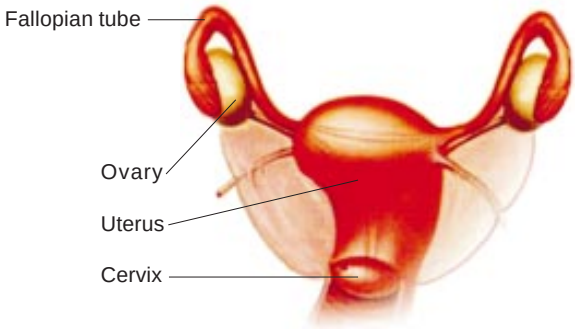


Fig. 5.7: Ovary.

Progesterone causes the uterine lining to thicken in preparation for pregnancy. Together, progesterone and estrogens are responsible for the changes that occur in the uterus during the female menstrual cycle.

5.3 CONTROL OF HORMONE PRODUCTION

Endocrine glands release hormones in response to one (or more) of the following stimuli:

- Hormones form other endocrine glands.
- Chemical characteristics of the blood (other than hormones).
- Neural stimulation.

Most hormone production is regulated by a **negative feedback** system. The nervous system and certain endocrine tissues monitor various internal conditions of the body. If action is necessary to maintain homeostasis, hormones are released, either directly by an endocrine gland or indirectly though the action of the hypothalamus of the brain, which stimulates other endocrine glands to release hormones. The hormones activate target cells, which initiate physiological changes that adjust body conditions. When normal conditions have been restored, the corrective action—the production of hormones—is discontinued. Thus, in negative feedback, when the original (abnormal) condition has been repaired, or negated, corrective actions decrease (or are discontinued). For example, the amount of glucose in the blood regulates the secretion of insulin and glucagons through negative feedback.

The production of some hormones is regulated by **positive feedback**. In such a system, hormones cause a condition to intensify (rather than decrease). As the condition intensifies, hormone production increases. Such positive feedback is

Table 5.1: Types of hormones and their functions.

Source	Hormone (H), Releasing Hormone (RH), or Inhibiting Hormone (IH)	Target	Action
Hypothalamus			
GHRH	Growth hormone RH	anterior pituitary	inhibits release of hGH
GHIH	Growth hormone IH (somatostatin)	anterior pituitary	stimulates release of hGH
TRH	Thyrotropin RH	anterior pituitary	stimulates release of TSH and hGH
GnRH	Gonadotropin RH	anterior pituitary	stimulates release of LH and FSH
PRH	Prolactin RH	anterior pituitary	stimulates release of PRL
PIH	Prolactin IH (dopanmine)	anterior pituitary	inhibits release of PRL
CRH	Corticotropin RH	anterior pituitary	stimulates release of ACTH
Anterior pituitary (tropic hormones)			
TSH	Thyroid stimulating H (thyrotropin)	thyroid	stimulates secretion of T_3 and T_4
ACTH	Adrenocortico-tropic hormone	adrenal cortex	stimulates secretion of glucocorticoids
FSH	Follicle-stimulating hormone	ovary, testes	regulates oogenesis and spermatogenesis
LH	Luteinizing hormone	ovary, testes	regulates oogenesis and spermatogenesis

Contd...

Anterior pituitary (hormones)			
PRL	Prolactin	mammary glands	stimulates production of milk
hGH	Human growth H (somatotropin)	bone, muscle, various	stimulates growth
Posterior pituitary			
OT	Oxytocin	uterus, mammary glands	uterine contractions, release of milk
ADH	Antidiuretic H (vasopressin)	kidneys, sweat glands	increases water retention
Thyroid gland			
T_4	Thyroxine	most body cells	increases rate of cellular metabolism
T_3	Triiodothyronine	bone	increases rate of cellular metabolism
	Calcitonin	bone	decreases blood Ca^{2+}
Parathyroid gland			
PTH	Parathyroid hormone	bone, kidneys, intestine	increases blood Ca^{2+}
Adrenal medulla			
NE	Epinephrine (adrenaline)	blood vessels, liver, heart	increases blood sugar, constricts blood vessels (fight-or-flight response)
NE	Norepinephrine (noradrenaline)	blood vessels, liver, heart	increases blood sugar constricts blood vessels (fight or flight response)
Adrenal cortex			
	Mineralocorticoids (e.g., aldosterone)	kidneys	increase reabsorption of Na^+, excretion of K^+
	Glucocorticoids (e.g., cortisol)	most body cells	increase blood sugar
	androgens (e.g., DHEA)	general	stimulate onset of puberty, female sex drive
Pancreas			
	Glucagon (secreted by alpha cells)	liver	increases blood glucose
	insulin (secreted by beta cells)	liver, muscle, adipose	decreases blood glucose
	Somatostatin (secreted by delta cells)	alpha and beta cells	inhibits insulin and glucagon release
	Pancreatic polypeptide (from F cells)	delta cells	inhibits somatostatin and pancreatic enzymes

Contd...

Ovaries			
	Estrogen	uterus, general	menstrual cycle, secondary sex characteristics
	Progesterone	uterus	regulates menstrual cycle, pregnancy
	Relaxin	pelvis, cervix	dilates cervix and birth canal
	Inhibin	anterior pituitary	inhibits FSH release
Testes			
	Testosterone	testes, general	spermatogenesis, secondary sex characteristics
	Inhibin	anterior pituitary	inhibits FSH release
Pineal			
	Melatonin	various	regulates biological clock
Kidney			
	Erythropoietin	bone marrow	increases blood cell production
	Calcitriol (Vitamin D)	intestine	increases Ca^{2+} absorption
Placenta			
	Estrogen	uterus	maintains pregnancy, mammary glands
	Progesterone	uterus	maintains pregnancy, mammary glands
	hCG	ovary	stimulates release of estrogen and progesterone
	hCS	mammary glands	prepares mammary glands for lactation
Gastrointestinal tract			
	Gastrin	stomach	stimulates HCI release
GIP	Gastrin inhibitory peptide	stomach, pancreas	inhibits gastric juice release, increases insulin
	Secretin	pancreas, liver	stimulates release of enzymes and bile
CCK	Cholecystokinin	pancreas, liver	stimulates release of enzymes and bile
	Serotonin	stomach	stimulates stomach muscle contraction
Heart			
ANP	Atrial natriuretic peptide	kidney, adrenal cortex	decreases blood pressure
Most cells			
PG	Prostaglandins	all cells except red blood cells	various
LT	Leukotrienes	all cells except red blood cells	various

uncommon but does occur during childbirth (hormone levels build with increasingly intense labor contractions) and lactation (where hormone levels increase in response to nursing, which causes milk production to increase).

5.4 EFFECT OF HYPER AND HYPO SECRETIONS

Endocrine disorders are commonly caused by tumours or autoimmune diseases and their effects are usually the result of **Hypersecretion** (Overproduction) and **Hyposecretion** (Under production) of hormones. The effects of many conditions are therefore readily linked to underlying abnormality.

Disorders of the Anterior Pituitary

Hypersecretion of AP hormones: The most common cause is prolonged hypersecretion of growth hormone(GH). The conditions are occasionally due to GHRH secreted by hypothalamus. As tumour increases in size, compression of nearby structure may lead to: hypersecretion of other pituitary hormones of both anterior and posterior lobes and even may damage the optic nerves, causing visual disturbances.

Effect of GH includes excessive growth of bones, enlargement of internal organs, growth of excess connective tissue, enlargement of heart rise in the blood pressure and reduced glucose tolerance and a predisposition to diabetes mellitus.

Gigantism: This occurs in children if GH is in excess while epiphyseal cartilage of bones are still growing and individual may grow to 2.1 to 2.4 m heights.

Acromegaly occurs in adults when there is excess GH after ossification is complete. So, bones become anormally thick and there is thickening of the soft tissues.

Hyposecretion of anterior pituitary hormones: It leads to tumours of the hypothalamus of pituitary, trauma, usually caused by fractured base of skull or surgery.

Disorders of posterior pituitary: It causes **Diabetes insipidus,** which is relatively rare condition usually caused by hyposecretion of ADH due to damage to the hypothalamus by trauma or encephalitis. Water reabsorption by renal tubules is impaired, leading to excretion of excessive amounts of dilute urine more than 10 litres a day leading to dehydration.

Disorders of the thyroid gland: These fall into three main categories: (i) Abnormal secretion of thyroid hormones (hyperthyroidism, hypothyroidism), (ii) Goitre-enlargement of the thyroid gland, (iii)Tumours.

Insufficient dietary iodine also causes deficiency in thyroid hormone production. The main effects are caused by an abnormally high or low basal metabolic rate.

Hyperthyroidism: In this body tissues are exposed to excessive levels of T3 and T4. Cardiac failure in adult is common due to aging Heart works harder to deliver more blood and nutrients.

Hypothyroidism: The occurs when there is insufficient T3 and T4 secretion causing congenital hypothyroidism in children and myxoedema in adults.

Disorders of the parathyroid glands: Excess secretion of parathyroid hormone(PTH) causes reabsorption of calcium from bones, raising the blood calcium level(hyperglycemia). The effects may be polysuria, constipation, muscle weakness and general fatigue. Deficiency of PTH causes **hypoparathyroidism**. Low level of calcium in the blood may cause psychiatric disturbances, development of cataract and brittle nails etc.

Hypersecretion of glucocorticoids: Cortisol is the main glucocorticoid hormone secreted by the adrenal cortex. Physiological effects may be painful adiposity of the face, exces protein breakdown causing thinning of subcutaneous tissue and muscle wasting of limbs.

CHAPTER 6

Reproductive System

"Journey of life completes with the progeny
Efficient trait transfer is the ultimate destiny
Life forms reproduce with unique harmony"

6.1 INTRODUCTION

All living things reproduce. Reproduction is the process by which organisms make more organisms like themselves. It is one of the things that sets living things apart from nonliving things. But even though the reproductive system is essential to keeping a species alive, unlike in the human reproductive process, two kinds of **sex cells**, or **gametes**, are involved. The male gamete, or **sperm**, and the female gamete, the **egg** or **ovum**, meet in the female's reproductive system to create a new individual. Both the male and female reproductive systems are essential for reproduction.

Humans, like other organisms, pass certain characteristics of themselves to the next generation through their **genes**, the special carriers of human traits. The genes parents pass along to their offspring are what make kids similar to others in their family, but they are also what make each child unique. These genes come from the father's sperm and the mother's egg, which are produced by the male and female reproductive systems.

Most species have two sexes: male and female. Each sex has its own unique reproductive system. They are different in shape and structure, but both are specifically designed to produce, nourish, and transport either the egg or sperm.

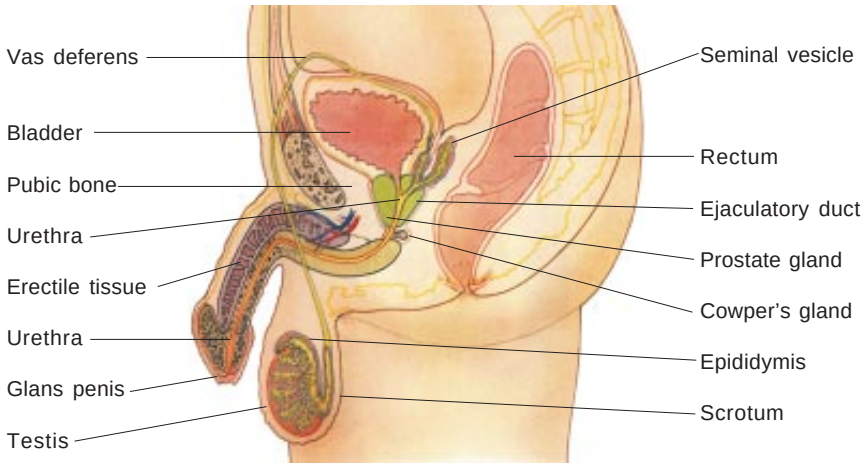


Fig. 6.1: Male reproductive system

6.2 MALE REPRODUCTIVE SYSTEM

Unlike the female, whose sex organs are located entirely within the pelvis, the male has reproductive organs, or **genitals**, which are both inside and outside the pelvis. The male genitals include:

1. The testicles, the duct system, which is made up of the epididymis and the vas deferens
2. The accessory glands, which include the seminal vesicles and prostate gland
3. The penis

In a guy who has reached sexual maturity, the two **testicles**, or **testes**, produce and store millions of tiny sperm cells. The testicles are oval-shaped and grow to be about 2 inches (5 centimeters) in length and 1 inch (3 centimeters) in diameter. The testicles are also part of the endocrine system because they produce hormones, including **testosterone**. Testosterone is a major part of puberty in boys, and as a guy makes his way through puberty, his testicles produce more and more of it. Testosterone is the hormone that causes boys to develop deeper voices, bigger muscles, and body and facial hair, and it also stimulates the production of sperm.

Alongside the testicles are the **epididymis** and the **vas deferens**, which make up the duct system of the male reproductive organs. The vas deferens is a muscular tube that passes upward alongside the testicles and transports the sperm-containing fluid called **semen**. The epididymis is a set of coiled tubes (one for each testicle) that connects to the vas deferens.

The epididymis and the testicles hang in a pouch-like structure outside the pelvis called the **scrotum**. This bag of skin helps to regulate the temperature of testicles, which need to be kept cooler than the body temperature to produce sperm. The scrotum changes size to maintain the right temperature. When the body is cold, the scrotum shrinks and becomes tighter to hold in the body heat. When the body is warm, the scrotum becomes larger and more floppy to get rid of extra heat. This happens without a guy ever having to think about it. The brain and the nervous system give the scrotum the cue to change size.

The **accessory glands**, including the seminal vesicles and the prostate gland, provide fluids that lubricate the duct system and nourish the sperm. The **seminal vesicles** are sac-like structures attached to the vas deferens to the side of the bladder. The **prostate gland**, which produces some of the parts of semen, surrounds the ejaculatory ducts at the base of the **urethra**, just below the bladder. The urethra is the channel that carries the semen to the outside of the body through the penis. The urethra is also part of the urinary system because it is also the channel through which urine passes as it leaves the bladder and exits the body.

The **penis** is actually made up of two parts: the **shaft** and the **glans**. The shaft is the main part of the penis and the glans is the tip (sometimes called the head). At the end of the glans is a small slit, an opening, from where semen and urine exit the body through the urethra. The inside of the penis is made of a spongy tissue that can expand and contract.

All boys are born with a **foreskin**, a fold of skin at the end of the penis covering the glans. Some boys are **circumcised**, which means that a doctor or clergy member cuts away the foreskin. Circumcision is usually performed during a baby boy's first few days of life. Although circumcision is not medically necessary, parents who choose to have their children circumcised often do so based on religious beliefs, concerns about hygiene, or cultural or social reasons. Boys who have circumcised penises and those who donot have are no different: All penises work and feel the same, regardless of whether the foreskin has been removed.

Functions

The male sex organs work together to produce and release semen into the reproductive system of the female during sexual intercourse. The male reproductive system also produces sex hormones, which help a boy develop into a sexually mature man during **puberty**.

When a baby boy is born, he has all the parts of his reproductive system in place, but it is not until puberty that he is able to reproduce. When puberty begins, usually

between the ages of 10 and 14, the **pituitary gland**—which is located near the brain—secretes hormones that stimulate the testicles to produce testosterone. The production of testosterone brings about many physical changes. Although the timing of these changes is different for every guy, the stages of puberty generally follow a set sequence.

1. During the first stage of male puberty, the scrotum and testes grow larger.
2. Next, the penis becomes longer, and the seminal vesicles and prostate gland grow.
3. Hair begins to appear in the pubic area and later it grows on the face and underarms. During this time, a male's voice also deepens.
4. Boys also undergo a growth spurt during puberty as they reach their adult height and weight.

A male who has reached puberty will produce millions of sperm cells every day. Each sperm is extremely small: only 1/600 of an inch (0.05 millimeters long). Sperm develop in the testicles within a system of tiny tubes called the **seminiferous tubules**. At birth, these tubules contain simple round cells, but during puberty, testosterone and other hormones cause these cells to transform into sperm cells. The cells divide and change until they have a head and short tail, like tadpoles. The head contains genetic material (genes). The sperm use their tails to push themselves into the epididymis, where they complete their development. It takes sperm about 4 to 6 weeks to travel through the epididymis.

The sperm then moves to the vas deferens, or sperm duct. The seminal vesicles and prostate gland produce a whitish fluid called **seminal fluid**, which mixes with sperm to form semen when a male is sexually stimulated. The penis, which usually hangs limp, becomes hard when a male is sexually excited. Tissues in the penis fill with blood and it becomes stiff and erect (an erection). The rigidity of the erect penis makes it easier to insert into the female's vagina during sexual intercourse. When the erect penis is stimulated, muscles around the reproductive organs contract and force the semen through the duct system and urethra. Semen is pushed out of the male's body through his urethra, a process called **ejaculation**. Each time a guy ejaculates, it can contain up to 500 million sperm.

When the male ejaculates during intercourse, semen is deposited into the female's vagina. From the vagina the sperms make their way up through the cervix and move through the uterus with help from uterine contractions. If a mature egg is in one of the female's fallopian tubes, a single sperm may penetrate it, and **fertilization**, or **conception**, occurs.

This fertilized egg is now called a **zygote** and contains 46 chromosomes — half from the egg and half from the sperm. The genetic material from the male and female has combined so that a new individual can be created. The zygote divides again and again as it grows in the female's uterus, maturing over the course of the pregnancy into an embryo, a fetus, and finally a newborn baby.

Sperm Count

Sperm count measures how many sperm are in a man's ejaculate. Anything over 20 million sperm per milliliter is considered normal. Anything less is considered oligospermia. A vasectomy is considered successful if the sample is azoospermic, or if only rare non-motile sperm are observed (fewer than 100,000 per milliliter).

Characteristics of Sperm

Motility

The motility of the sperm is evaluated. WebMD defines normal motility as 60% of observed sperm, or at least 8 million per milliliter, showing good forward movement. For instance, a man can have a total amount (sperm count) of far over the limit of 20 million sperm cells per milliliter, but still have bad quality, because too few of them are motile. However, if the sperm count is very high, then a motility of less than 60% might not matter, because the fraction might still be more than 8 million per milliliter. The other way around, a man can have a sperm count far less than 20 million sperm cells per milliliter and still have good motility, if more than 60% of those observed sperm cells show good forward movement.

The World Health Organization (WHO) criteria are that normal motility is when at least 50% of observed sperm move forward normally.

Morphology

The morphology of the sperm is also evaluated. According to WHO criteria, a sample is normal if 30% or more of the observed sperm have normal morphology. If morphology is evaluated using the strict criteria developed by Dr. Thinus Kruger, a sample is normal if 14% or more of the observed sperm have normal morphology.

Volume

The volume of the sample measured advises that volumes between 1.0 mL and 6.5 mL are normal. WHO criteria specify that any volume greater than 2.0 mL is normal. Low volume may indicate partial or complete blockage of the seminal vesicles, or that the man was born without seminal vesicles.

Fructose level

The level of fructose in the semen is measured normally as at least 300 $^{mg}/_{mL}$. WHO specifies a normal level of 13 µmol per sample. Absence of fructose may indicate a problem with the seminal vesicles.

pH

The pH of the sample is measured as the normal range of 7.1-8.0. WHO criteria specify normal as 7.2-7.8. Acidic ejaculate (lower pH value) may indicate that one or both of the seminal vesicles are blocked. A basic ejaculate (higher pH value) may indicate an infection. A pH value outside the normal range is harmful to sperm.

Preservation of sperms

There are situations in life when the depositing of sperm in a long-term storage bank offers options for future preservation and peace of mind. The two primary reasons for sperm freezing are long-term preservation for later use by depositors and availability of sperm for donor insemination.

There are a number of reasons men should consider sperm cryopreservation:

6.3 FEMALE REPRODUCTIVE SYSTEM

The organs of the female reproductive system produce and sustain the female sex cells (egg cells or ova), transport these cells to a site where they may be fertilized by sperm, provide a favorable environment for the developing fetus, move the fetus to the outside at the end of the development period, and produce the female sex hormones. The female reproductive system includes the ovaries, Fallopian tubes, uterus, vagina, accessory glands, and external genital organs.

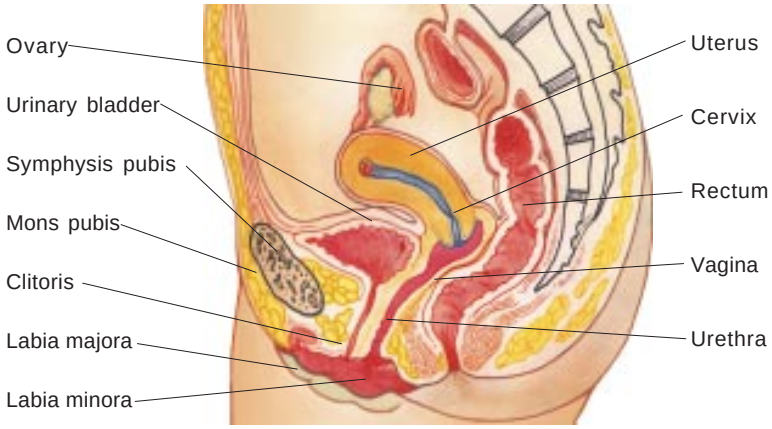


Fig. 6.2: Female reproductive system.

Uterine Tube (Fallopian tube)

The **Fallopian tubes**, are also known as **oviducts**, **uterine tubes**. There are two Fallopian tubes, one on each side. They transport the egg from the ovary to the uterus (the womb). The Fallopian tubes have small hair-like projections called cilia on the cells of the lining. These tubal cilia are essential for the movement of the egg through the tube into the uterus. If the tubal cilia are damaged by infection, the egg may not get 'pushed along' normally but may stay in the tube.

Motility

The Fallopian tubes are mobile, and have been observed on time-lapse. Although anatomical illustrations have them proceeding from the uterine horns to the ovary, this is not the case for most of the menstrual cycle, and a tube may cross to the other side or lie on top of the uterus.

Function in Fertilization

When an ovum is developing in an ovary, it is encapsulated in a sac known as an ovarian follicle.

On maturity of the ovum, the follicle and the ovary's wall rupture, allowing the ovum to escape and enter the Fallopian tube. There it travels towards the uterus, pushed along by movements of cilia on the inner lining of the tubes. This trip takes hours or days. If the ovum is fertilized while in the Fallopian tube, then it normally implants in the endometrium when it reaches the uterus, which signals the beginning of pregnancy. Occasionally, the embryo implants into the Fallopian tube instead of the uterus, creating an ectopic pregnancy, commonly known as a "tubal pregnancy".

Uterus

The **uterus** (from the Latin for *womb*) is the major female reproductive organ of most mammals, including humans. One end, the cervix, opens into the vagina; the other is connected on both sides to the fallopian tubes. The term *uterus* is commonly used within the medical and related professions, whilst *womb* is in more common usage. The plural of uterus is uteri.

The uterus is located in the pelvis, immediately dorsal (and usually somewhat cranial) to the urinary bladder and ventral to the rectum. It is held in place by several ligaments. Outside of pregnancy, its size is several centimeters in diameter. The uterus mostly consists of muscle. The innermost permanent layer of tissue is called the endometrium. In most mammals, including humans, the endometrium builds a lining periodically which, if no pregnancy occurs, is shed or reabsorbed. Shedding of the endometrial lining in humans is responsible for menstrual bleeding (known colloquially as a woman's

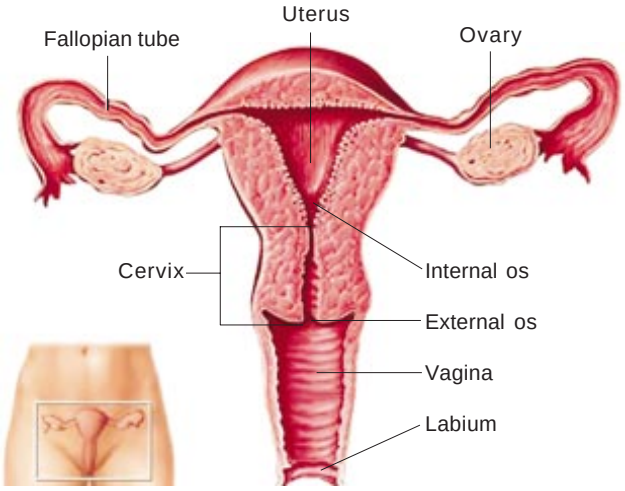


Fig. 6.3: Structure of uterus.

"period") throughout the fertile years of a female. In other mammals there may be cycles set as widely apart as six months or as frequently as a few days.

The main function of the uterus is to accept a fertilized ovum which becomes implanted into the endometrium, and derives nourishment from blood vessels which develop exlusively for this purpose. The fertilized ovum becomes an embryo, develops into a fetus and gestates until birth. Due to anatomical barriers such as the pelvis, the uterus is pushed partially into the abdomen due to its expansion during pregnancy. Even in pregnancy, the mass of a human uterus amounts to only about a kilogram (2.2 pounds).

Vulva

The **vulva** (from Latin, *vulva*, plural *vulvae* or *vulvas*; see etymology) is the region of the external genital organs of the female, including the labia majora, mons pubis, labia minora, clitoris, bulb of the vestibule, vestibule of the vagina, greater and lesser vestibular glands, and vaginal orifice.

The vulva has many major and minor anatomical structures. Its development is done in several phases; fetal and pubertal periods are the most important. True door of the human matrix, it protects its opening by a "double door": the labia majora and the labia minora as well as a vulval vestibule, and a normal microbial flora that flows from the inside out. However, regular hygiene permits a good vulvovaginal health. The vulva is more susceptible to infections than the penis.

These external body structures also have a sexual function; they are richly innervated and provide pleasure during sexual intercourse when properly stimulated. Since the

origin of the human society, the vulva has been the subject of various art performances depicting the power this organ has "to give life" (i.e., often confused and associated with the vagina in pre-historic periods and antiquity and less and less, as human science progressed), and the sexual pleasure it provides to the human kind.

In common speech, the term *vagina* is often used to refer to the vulva or female genitals generally, although, strictly speaking, the vagina is a specific internal structure, whereas the vulva is the exterior genitalia.

Most male and female sex organs originate from the same tissues in the development of a foetus. The vulva is no different. The anatomy of the vulva is related to the anatomy of the male genitalia by a shared developmental biology. Organs that have a common developmental ancestry in this way are said to be homologous.

The clitoral glans is homologous to the glans penis in males, and the clitoral body and the clitoral crura are homologous to the corpora cavernosa of the penis. The labia majora, labia minora and clitoral hood are homologous to the scrotum, shaft skin of the penis, and the foreskin, respectively. The vestibular bulbs beneath the skin of the labia minora are homologous to the corpus spongiosum, the tissue of the penis surrounding the urethra. The Bartholin's glands are homologous to Cowper's glands in males.

Structures

In human beings, major structures of the vulva are:

- the *mons pubis*
- the *labia*, consisting of the *labia majora* and the *labia minora*
- the external portion of the clitoris and the clitoral hood
- the opening (or meatus) of the urethra

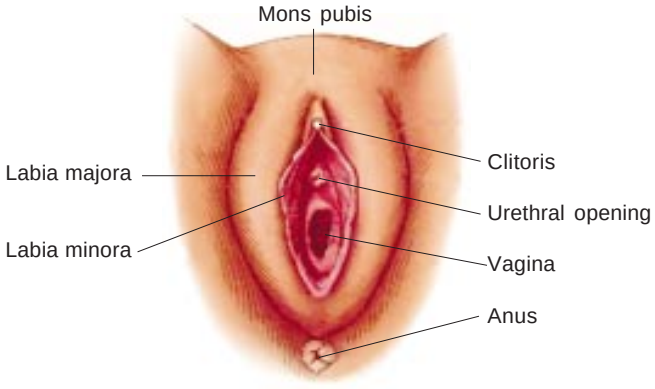


Fig. 6.4: Diagrammatic view of vulva.

- the opening (or introitus) of the vagina
- the hymen.

Perineum

In human anatomy, the **perineum** is generally defined as the surface region in both males and females between the pubic symphysis and the coccyx. The perineum is the region of the body inferior to the pelvic diaphragm and between the legs.

A diamond-shaped area on the inferior surface of the trunk, which includes the anus and, in females, the vagina. Its definition varies: it can refer to only the superficial structures in this region, or it can be used to include both superficial and deep structures.

The perineum corresponds to the outlet of the pelvis.

The **anogenital distance** is a measure of male feminisation measuring the distance between the anus and the base of the penis. Studies show that the perineum is twice as long in males as in females. One research group stated that the AGD in males may be shortened through exposure to phthalates found in some plastics and personal care products, but the science behind this research has been questioned.

Areas of the perineum

The region of the perineum can be considered a distinct area from pelvic cavity, with the two regions separated by the pelvic diaphragm. The following areas are thus classified as parts of the perineal region:

- perineal pouches: superficial and deep (see above for details)
- Ischioanal fossa - a fat filled space at the lateral sides of anal canal. It is bounded laterally by obturator internus muscle, medially by pelvic diaphragm and anal canal. Its base is the skin.
- Anal canal
- Pudendal canal - contains internal pudendal artery and the pudendal nerve.

FEMALE REPRODUCTIVE CYCLE

Menstrual Phase: The female reproductive cycle is a monthly cycle that begins with menstruation (shedding of the endometrium, or uterine lining) and ends with either pregnancy or the beginning of another menstruation.

Proliferative Phase: Following the menstrual phase, when hormone levels drop off and the uterine lining is shed, the proliferative phase begins, and estrogens produced by the ovary begin to act on the female reproductive tissues. The endometrium thickens in preparation for implantation of a fertilized egg. Meanwhile, in the ovary, the cycle

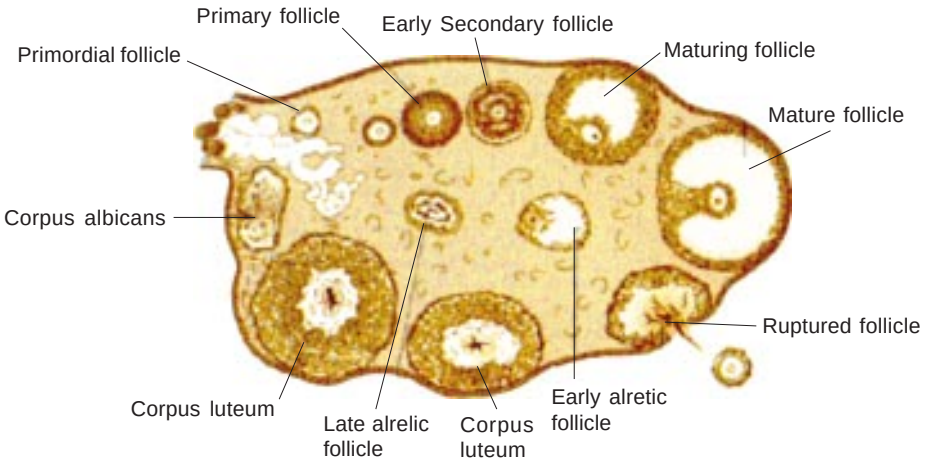


Fig. 6.5: Ovulation.

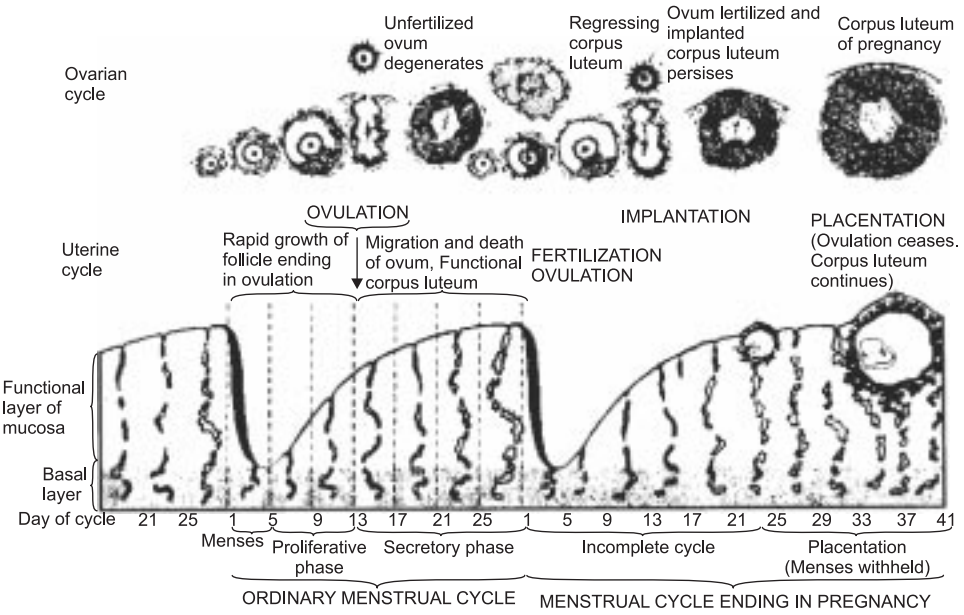


Fig. 6.6: Female reproductive cycle ending in pregnancy.

of ovulation is preparing for release of a mature oocyte, or egg. Developing from primary follicle, then a secondary follicle, and finally a mature follicle, the mature egg awaits hormonal signals that cause its release from the ovary. The increase in levels of estrogens produced by the ovary causes the hypothalamus to secrete a hormone GnRH, which in turn causes the anterior pituitary gland to secrete large amounts of the hormones FSH (Follicle Stimulating Hormone) and LH (Luteinizing Hormone).

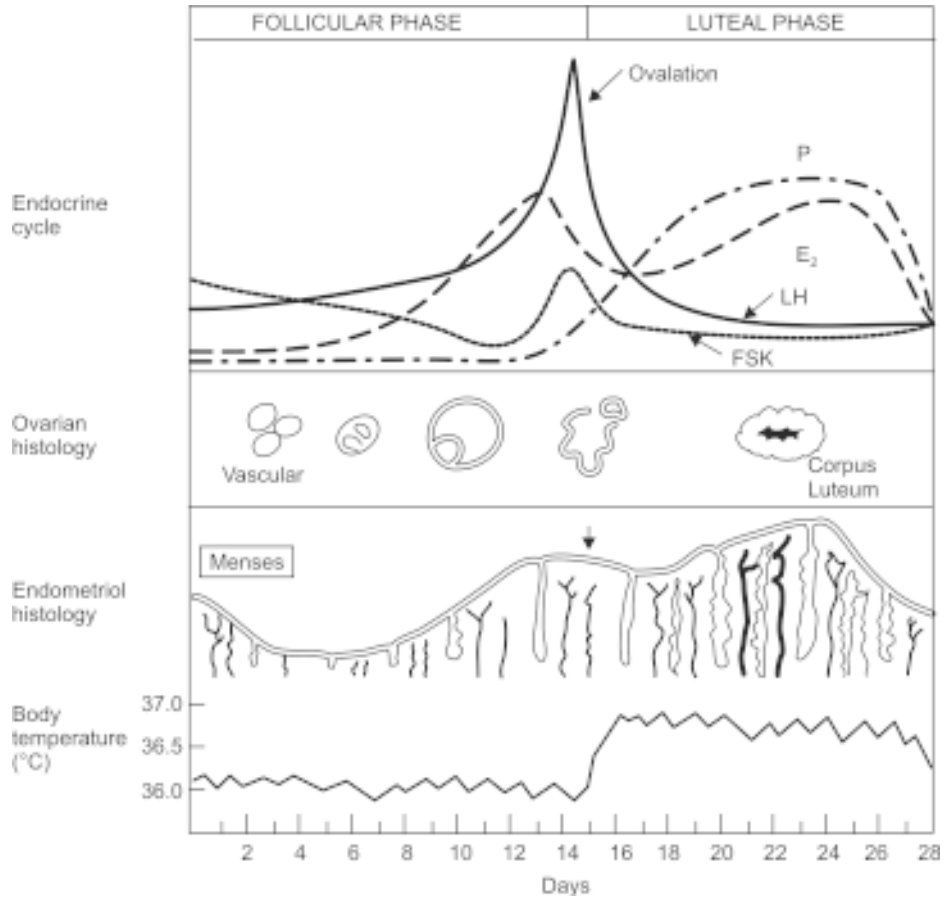


Fig. 6.7:

Ovulation: The LH surge causes the egg to be released from the mature follicle and the ovary itself. It is released into the body cavity where it is (almost always) caught by the fimbriae (finger-like projections) of the fallopian tube. From there it travels toward the uterus (Fig. 6.5), awaiting fertilization by a sperm.

Secretory Phase: Once the egg is released from the ovary, the mature follicle from which it erupted becomes the corpus luteum, which still secretes small amounts of estrogen. But the secretory phase is dominated by the hormone progesterone, which is produced by the cells of the ovary. The secretion of progesterone causes the endometrium to thicken and prepare for implantation of an embryo.

Fertilization and Implantation: If the egg is not fertilized by a sperm, the corpus luteum regresses, levels of estrogens and progesterones drop off, and the menstrual phase begins the reproductive cycle again. If the egg is fertilized by a sperm while

traveling down the fallopian tubes and the embryo implants into the wall of the uterus, the future placental tissues secrete chorionic gonadotropin, which maintains the corpus luteum. The corpus luteum of pregnancy, as it is now called, is responsible for producing the estrogens and progesterone required to maintain the pregnancy for the first few months of the pregnancy. After that point, the placenta itself produces enough estrogen and progesterone to maintain the pregnancy on its own.

Factors affecting fertility

Age: During the first decade of life, the reproductive system is in a juvenile state. At about age 10, hormone directed changes start to occur in both the sexes. Puberty is the period when secondary sexual characters begin to develop and the potential for sexual reproduction is reached. Onset of puberty is marked by pulses or bursts of LH and FSH secretion, each triggered by a pulse GnRH. Most pulses occur during sleep. As puberty advances, the hormone pulses occur during the day as well as at night. The pulses increase in frequency during a three to four year period until the adult pattern is established.

In females, the reproductive cycle normally occurs once each month from **menarche,** the first menses, to **Menopause,** the cessation of menses. Thus, the female reproductive system has a time limited span fertility between menarche and menopause.

With the age, fertility declines. Due to loss of estrogen, sexual desires (libido) does not show a parallel decline; it may be maintained by adrenal sex steroids. In males, declining reproductive function is much more subtle than female. Healthy man often retain reproductive capacity into their eighties or nineties. At about age 55 a decline in testosterone synthesis leads to fewer viable sperm and decreased sexual desire.

Lifestyle

Looking after your health as a prospective father is very important as a host of lifestyle factors can affect fertility potency. Some points of concern are,

Hot stuff

Testicles produce the best quality sperm when they keep their cool. “The boys” are happiest at 34.5-36 C or 94-96 degrees F, which is a couple of degrees cooler than normal body temperature. Working in a hot environment or sitting for long periods of time, however, have been linked to raise testicular temperature and abnormal sperm count or semen quality. Using a laptop on your lap, driving for long periods and sitting for long at your computer desk have also been linked to increased scrotal temperature.

Narrow seats in two wheelers

Impotence can be an unexpected and frightening side effect of riding scooters, motorbikes and bicycles for long hours on narrow seats. It has been found that the narrow seat's steady pressure on the groin area can damage arteries and nerves and result in erectile dysfunction (i.e., not being able to "get it up").

It is best to ensure that your bike or scooter has a wider padded seat that will spread the load. See a doctor if you feel any numbness or pain or have erection problems.

Stress

It seems that stress can affect the sperm count of some men. Stress has an effect on men who have a low sperm count. Stress has certainly, and unfortunately given the circumstances, been shown to have an impact on the quality of sperm of men in couples undergoing IVF.

Finally, if you have recently lost a close family member, then you may find that your fertility has taken a knock as well. Depending on your particular circumstances, simply relaxing may increase the potency. Yoga, meditation, and exercise have been found to be effective in reducing stress levels.

Smoking

Men who smoke damage the quantity and quality of their sperm. It may take longer for a woman to become pregnant, particularly if the concerned person smokes heavily; although passive smoking alone has been shown to have an impact on the time it takes for a woman to get pregnant.

Exercise

Moderate exercise does not affect the sperm count and is important for maintaining health, weight, and general well being. However, studies show that if a person follows a rigorous exercise routine, it can have a negative effect on the sperm count. Studies show that running more than 30 miles a week may affect the amount of sperm produced by the testicles.

Give it time

It takes about three months for the body to complete a cycle of sperm production, so any changes you start to make to your lifestyle today will take a while to come through in improved sperm. The bottom line is, if you commit yourself to a few months of clean, active living and healthy eating — that means plenty of fruits, vegetables, whole grains, low-fat dairy products, lean meats — and a safe (though admittedly tamer) lifestyle, you'll be in top shape to father a child.

Genetic Factors

Studies into the mechanisms underlying spermatogenesis, the process by which spermatogonia undergo meiosis to become spermatozoa, have identified a number of genetic determinants of male infertility. Genetic factors become more accountable for this phenotype. Some genetic factors for male infertility include: (i) autosomal and sex chromosomal abnormalities; (ii) genetic disorders associated with impaired gonadotrophin secretion or action; (iii) microdeletions within regions of the Y-chromosome containing candidate gene families for spermatogenesis; (iv) the genetic nexus between cystic fibrosis and congenital bilateral absence of the vas deferens.

Environmental Factors

The importance of these is harder to estimate. Smoking, drugs, alcohol, industrial pollution, occupation, dress, hot bath etc are known to depress sperm function.Exposure to low-level environmental contaminants such as phthalates, polychlorinated biphenyls (PCBs), dioxins, pesticides, and other chemicals may be subtly undermining our ability to reproduce.

Hormonal Factors

The female reproductive cycle is completely run by hormones. Without the hormones, conception would not occur. It is no wonder that if any of the key hormones are out of whack then infertility is the result. Maintaining a balance of this fine tuned system of glands and hormone excretions is paramount in the act of conception.

Estrogen prompts the cervix to produce the fertile quality cervical fluid. It controls the entire menstrual cycle. **FSH** is the hormone responsible for prompting the ovaries to produce mature ova or eggs – and the production of estrogen. **GnRH** stimulates the pituitary gland in the production of FSH and luetenizing hormone (LH). This helps in the lead to follicle development and ovulation. LH is released in one surge prior to ovulation, which in fact prompts ovulation to occur. Progesterone is produced by the corpus luteum after ovulation has occurred. **Progesterone** is responsible for the higher basal body temperatures. It helps to build and maintain the uterine lining for the fertilized egg and helps to keep the lining should pregnancy occur. Progesterone is also responsible for the drying up of the cervical fluid and for the change in cervical position during the second half of the reproductive cycle. **Prolactin** is produced during breastfeeding by the pituitary gland. Prolactin stimulates the production of milk and hinders ovulation. Sometimes the pituitary gland produces prolactin when breastfeeding is not occurring. This is known as an imbalance in hormones and the result is infertility.

All these hormones work together—being released at key moments throughout the cycle in order to bring about ovulation—the release of the egg from the ovary—and in

helping to prepare the body for possible pregnancy. Any imbalance in one or all of these hormones causes infertility.

MAMMARY GLANDS

Mammary glands are the organs that, in mammals, produce milk for the sustenance of the young. These exocrine glands are enlarged and modified sweat glands and give mammals their name.

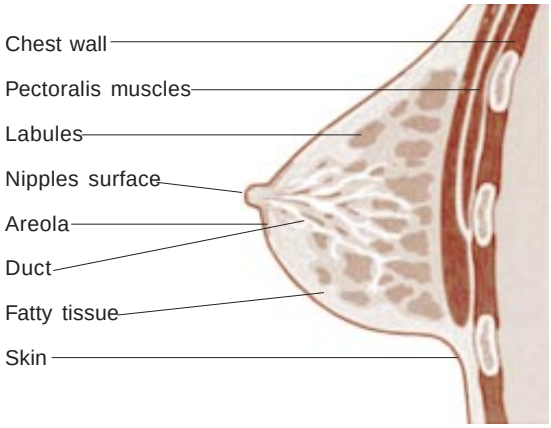


Fig. 6.8: Structure of mammary glands.

Structure

The basic components of the mammary gland are the *alveoli* (hollow cavities, a few millimetres large) lined with milk-secreting cuboidal cells and surrounded by myoepithelial cells. These alveoli join up to form groups known as *lobules*, and each lobule has a *lactiferous duct* that drains into openings in the nipple. The myoepithelial cells can contract, similar to muscle cells, and thereby push the milk from the alveoli through the lactiferous ducts toward the nipple, where it collects in widenings (*sinuses*) of the ducts. As the infant begins to suck, the hormonally mediated "let down reflex" ensues and the mother's milk is secreted into – not sucked from the gland by – the baby's mouth.

All the milk-secreting tissue leading to a single lactiferous duct is called a "simple mammary gland"; a "complex mammary gland" is all the simple mammary glands serving one nipple. Humans normally have two complex mammary glands, one in each breast, and each complex mammary gland consists of 10–20 simple glands. The presence of more than two nipples is known as polythelia and the presence of more than two complex mammary glands as polymastia.

Development and Hormonal Control

Mammary glands exist in both sexes, but are rudimentary until puberty when, in females, they begin to develop in response to ovarian hormones. Estrogen promotes formation, whereas testosterone inhibits it.

At the time of birth, the baby has lactiferous ducts but no alveoli. Little branching occurs before puberty when ovarian estrogens stimulate branching differentiation of the ducts into spherical masses of cells that will become alveoli. True secretory alveoli develop only in pregnancy, where rising levels of estrogen and progesterone cause further branching and differentiation of the duct cells, together with an increase in adipose tissue and a richer blood flow.

Colostrum is secreted in late pregnancy and for the first few days after giving birth. True milk secretion (lactation) begins a few days later due to a reduction in circulating progesterone and the presence of the hormone prolactin. The suckling of the baby causes the release of the hormone oxytocin which stimulates contraction of the myoepithelial cells.

In vitro Fertilization (IVF): Test Tube Baby

***In vitro* fertilisation** (**IVF**) is a technique in which egg cells are fertilised by sperm outside the woman's womb, *in vitro*. IVF is a major treatment in infertility when other methods of assisted reproductive technology have failed. The process involves hormonally controlling the ovulatory process, removing ova (eggs) from the woman's ovaries and letting sperm fertilise them in a fluid medium. The fertilised egg (zygote) is then transferred to the patient's uterus with the intent to establish a successful pregnancy.

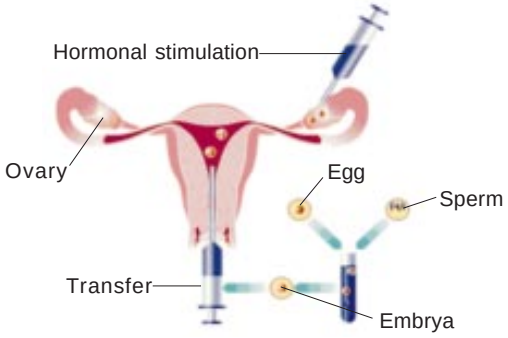


Fig. 6.9: *In vitro* fertilization.

In vitro

The term *in vitro*, from the Latin root meaning *in glass*, is used, because early biological experiments involving cultivation of tissues outside the living organism from which they came, were carried out in glass containers such as *beakers, test tubes, or petri dishes.* Today, the term *in vitro* is used to refer to any biological procedure that is performed outside the organism it would normally be occurring in, to distinguish it from an *in vivo* procedure, where the tissue remains inside the living organism within which it is normally found. A colloquial term for babies conceived as the result of IVF, ***test tube babies***, refers to the tube-shaped containers of glass or plastic resin, called *test tubes*, that are commonly used in chemistry labs and biology labs. However *in vitro* fertilisation is usually performed in the shallower containers called petri dishes. (Petri dishes may also be made of plastic resins.) However, the IVF method of Autologous Endometrial Coculture is actually performed on organic material, but is yet called *in vitro*.

CHAPTER 7

Digestive System

"Hunger tempts to eat
Furnish taste when you masticate
Synchronized process will digest
Cells gear up to captivate"

7.1 INTRODUCTION

The system used in the human body for the process of **digestion** is called digestive system. The human digestive system consists primarily of the **digestive tract**, or the series of structures and organs through which **food** and liquids pass during their processing into forms absorbable into the bloodstream. The system also consists of the structures through which wastes pass in the process.

The digestive system is the collective name used to describe the *alimentary canal*, some *accessory organs* and variety of digestive processes that take place at different levels in the canal to prepare the food eaten for absorption. All living organisms require nutritive substances and water for survival and growth. The substances must be broken into smaller particles and converted into absorbable materials by the process called **digestion.**

The functions of digestive system include:

1. Ingestion or consumption of food substances
2. Breaking them into small particles
3. Transport of the small particles to different areas of the digestive tract
4. Secretion of necessary enzymes and other substances for digestion

5. Digestion of food particles
6. Absorption of the digestive products(nutrients)
7. Removal of the unwanted substances from the body

7.2 PARTS OF THE DIGESTIVE SYSTEM

The digestive system is made up of gastrointestinal tract(GI tract) or alimentary canal and the accessory organs, which help in the process of digestion and absorption. GI tract is a tubular structure extending from mouth up to the anus with a length of about 30 feet. It opens to the external environment on both ends.

Parts of GI Tract: Mouth, pharynx, oesophagus, stomach, small intestine and large intestine.

Accessory Organs of the Digestive System: Teeth, tongue, salivary glands, exocrine part of pancreas, liver and gallbladder.

Wall of Gastrointestinal Tract: It is generally composed of **mucus layer,** which is the innermost layer, also called gastrointestinal mucosa or mucous membrane. **Submucus layer** is present from esophagus onwards. It is absent in mouth and pharynx. It contains collagen fibers, reticular fibers and few cells of connective tissue. **Muscular layer** The lips, cheeks and wall of the pharynx have skeletal muscle and esophagus has both skeletal and smooth muscle fibers. Wall of stomach and intestine is formed by smooth muscle fibers. **Serous or fibrous layer** is the outermost layer of GI tract, either serous or fibrous in nature. The serous layer formed by connective tissue and mesoepithelial cells is also called serosa. The fibrous layer is otherwise called fibrosa. It is formed by connective tissue and covers pharynx and esophagus.

Nerve supply to GI tract is by both intrinsic nerve supply and extrinsic nerve supply. The activities of the digestive system can be grouped under five main headings.

Ingestion: This is the taking of the food into the alimentary tract, i.e., eating and drinking.

Propulsion: This mixes and moves the contents along the alimentary tract.

Digestion: This consists of mechanical breakdown of food by mastication (chewing) and chemical digestion of food into small molecules by enzymes present in secretion produced by glands and accessory organs of the digestive system.

Absorption: This is the process by which digested food substances pass through the walls of some organs of the alimentary canal into the blood and lymph capillaries for circulation and use by body cells.

Elimination: Food substances that have been eaten but cannot be digested and absorbed are excreted from the alimentary canal as faeces by the process of defaecation.

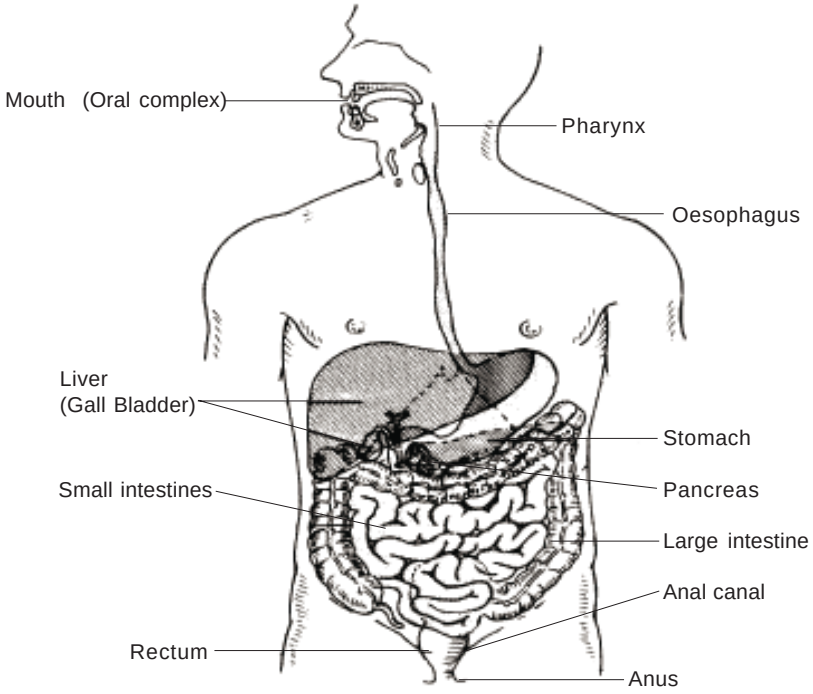


Fig. 7.1: Digestive system of human.

7.3 FUNCTIONAL ANATOMY OF DIGESTIVE SYSTEM

Mouth

The mouth is also known as oral cavity or buccal cavity. It is formed by cheeks, lips and palate and encloses teeth and tongue. The functions of the mouth are, ingestion of food material, chewing and mixing of food with saliva, appreciation of taste of food and transfer of bolus to esophagus.

***Salivary glands*:** In humans, saliva is secreted by three major and some minor salivary glands in the oral and pharyngeal mucous membrane. The major glands are:

***Parotid glands*:** These are the largest of the salivary glands situated at the side face just below and in front of the ear.

***Submaxillary glands*:** These are otherwise known as submandibular and glands are located in submaxillary triangle medial to mandible.

***Sublingual glands*:** These are the smallest of the three pairs of major salivary glands and are situated in the mucosa at the floor of the mouth.

Properties of Saliva:

1. **Volume: 1000** to 1500 ml of saliva is secreted per day and is approximately about 1ml/minute
2. **Reaction:** Mixed saliva from all the glands is slightly acidic with p^H of 6.35 to 6.85.
3. **Specific gravity:** It ranges between 1.002 and 1.012
4. **Tonocity:** Saliva is hypotonic to plasma.

Composition of the Saliva: It contains 99.5% water and 0.5% solids.

Functions of Saliva: Saliva is very essential as its absence leads to many inconveniences.

1. **Preparation of food for swallowing:** When the food enters the mouth, saliva moistens and dissolves it. The mucous membrane of mouth is also moistened by saliva, which lubricates the bolus and facilitates the swallowing.
2. **Appreciation of taste:** As taste is chemical sensation, saliva by its solvent action dissolves the solid food substances which can stimulate the taste buds. The stimulated taste buds recognize the taste.
3. **Digestive function:** Saliva has three digestive enzymes namely, salivary amylase, maltase and lingual lipase. Salivary amylase is a carbohydrate splitting (amylolytic) enzyme. It acts on starch and converts it into dextrin and maltose. The optimum p^H necessary is 6.00. But it cannot act on cellulose. Maltase enzyme is present only in traces in human saliva, which converts maltose to glucose. Lingual lipids are secreted in serous glands situated on the posterior aspect of tongue that digests milk fats and hydrolyses triglycerides into fatty acids and 1,2-diacylglycerol.
4. **Cleansing and protective function:** Due to constant secretion of saliva, mouth and teeth are rinsed and kept free from debris. The enzyme lysozyme of saliva kills some bacteria such as *Staphylococcus* etc. and musin helps in lubrication.
5. **Role in speech:** By moistening and lubricating the soft parts of the mouth and lips, saliva helps in speech.
6. **Excretory function:** Both organic and inorganic substances are excreted. It specifically excretes mercury, potassium iodide, lead and thiocyanate.
7. **Regulation of water balance:** When body water content decreases, salivary secretion also decreases, which causes dryness of the mouth and induces thirst. When water is taken, it quenches thirst and restores body water content.

Pharynx

The pharynx is divided for descriptive purpose into three parts—the nasopharynx, oropharynx and laryngopharynx—passages common to both the respiratory and digestive system. Pharynx has three layers. The lining membrane (mucosa) with stratified epithelium, middle layer consists of fibrous tissue and outer layer consists of number of involuntary muscles involved in swallowing. Blood supply is by several branches of facial arteries, venous drainage is into facial veins and the internal jugular veins. Nerve supply is from the pharyngeal plexus and consists of parasympathetic and sympathetic nerves.

Oesophagus

Oesophagus is about 25 cm long and 2cm in diameter and lies in the median plane in the thorax in front of the vertebral column behind the trachea and heart. It continues with pharynx and just below the diaphragm it joins the stomach. The oesophagus has sharp angle which helps in regurgitation(backflow) of gastric contents into the oesophagus. The upper and lower ends of the oesophagus are closed by sphincter.

Structure. It has four layers of tissue. The outer layer covering is the adventitia, which consists of elastic fibrous tissue that attaches the oesophagus to the surrounding structures. The proximal third is lined by stratified squamous epithelium and the distal third by columnar epithelium. The middle third is lined by the mixture of two.

Functions of the Mouth, Pharynx and Oesophagus

Formation of a bolus: When food is taken into the mouth, it is masticated by teeth and moved round the mouth by the tongue and muscles of the cheeks. It is mixed with saliva and forced into a soft mass or bolus ready for swallowing.

Swallowing (Deglutition): This occurs in three stages after mastication is complete and bolus has been formed. It is initiated voluntarily but completed by reflex (involuntary) action.

1. The mouth is closed and voluntary muscles of the tongue and cheeks push the bolus backwards into the pharynx.
2. The muscles of the pharynx are stimulated and involuntary contraction of these muscles propels the bolus down into the oesophagus. All other routes that the bolus could take are closed. Larynx is lifted up forward so that its opening is occluded by overhanging epiglottis preventing entry into air way (trachea).

Stomach

Stomach is a hollow organ situated just below the diaphragm on the left side of the abdominal cavity. Its volume is 50ml when empty and can accommodate upto 1–1.5 liters of solids and liquids.

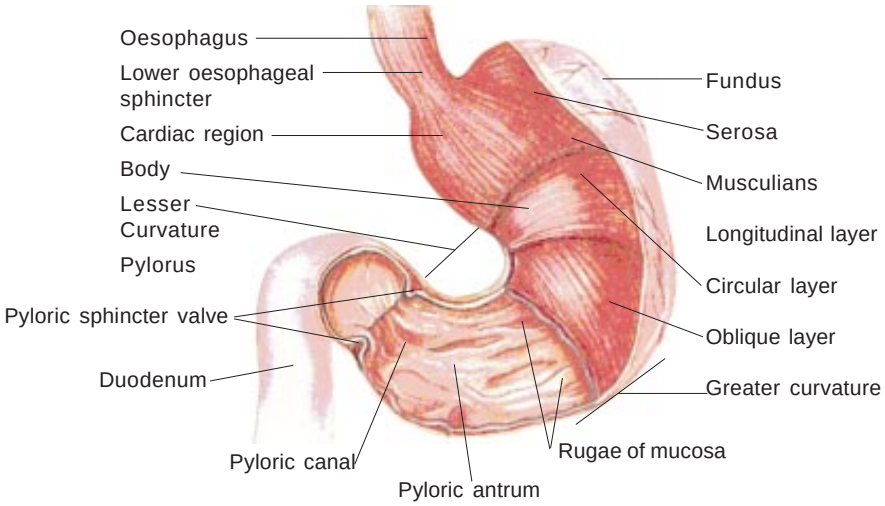


Fig. 7.2: Parts of Stomach.

Parts of the Stomach

1. **Cardiac region:** It is the upper part of the stomach where oesophagus opens. It is guarded by sphincter called cardiac sphincter, which opens only towards the stomach.
2. **Fundus:** It is a small dome-shaped structure. It is elevated above the level of the cardiac region.
3. **Body or corpus:** It is the largest part, about 75 to 80% of the whole stomach.
4. **Pyloric region:** It has two parts—antrum and pyloric canal. Body of the stomach ends in antrum and is continued as the narrow pyloric canal, which opens into first part of small intestine called duodenum.

Structure of stomach wall

The wall of the stomach has 4 layers:

1. Outer serous layer—formed by peritoneum which covers the stomach except at the lesser and greater curvatures.
2. Muscular layer—made of three layers of the smooth muscle fibers namely, inner oblique, middle circular and outer longitudinal layers.

3. Submucus layer—formed by areolar tissue, blood vessels, lymph vessels and meissner's nerve plexus.
4. Inner mucus layer—lined by mucus secreting columnar epithelial cells. The gastric glands are situated in this layer.

Glands of the stomach

The glands of the stomach are the gastric glands, which are tubular structures made up of different types of cells. These are classified into three types on the basis of their location in the stomach.

1. Fundic glands—situated in body and fundus of stomach. Fundic glands are also called main gastric glands or oxyntic glands.
2. Pyloric glands- present in pyloric part of the stomach.
3. Cardiac glands- located in the cardiac region of the stomach.

Functions of stomach

1. Mechanical function

(i) **Storage function:** The food is stored in the stomach for long time i.e., 3-4 hours and then emptied into the intestine slowly.

(ii) **Formation of chyme:** The peristaltic movement of stomach mixes the bolus with gastric juice and converts it into a semisolid material known as chyme.

2. Digestive function

The gastric juice present acts mainly on proteins. The proteolytic enzymes are pepsin and rennin and it also contains some other enzymes like gastric lipase, gelatinase, urase and gastric amylase.

Pepsin is a major proteolytic enzyme of gastric juice. This secreted as pepsinogen that is coverted to pepsin by HCl which is secreted in parietal cells.

Gastric lipase is a weak lipolytic enzyme inactive below pH 2.5 and active at 4-5. It acts on tributyrin (Butter fat) and hydrolyses it into fatty acids and glycerols.

Action of other enzymes (i) Gelatinase degrades proteoglycans in meat into peptides.

(ii) Urase — acts on urea and produces ammonia (iii) Gastric amylase — degrades starch (iv) Renin — curdles milk present only in animals.

3. Hemopoietic function

The intrinsic factor of castle present plays role in erythopoiesis. It is necessary for absorption of vit. B_{12} form GI tract into the blood which is an important maturation factor during erythropoiesis.

4. Protective function

The thick mucus present in the gastric juice is responsible for the protection of gastric wall due to mucoprotein secreted by mucus neck cells.

Functions of hydrochloric acid

(i) Activates pepsinogen into pepsin.

(ii) Kills bacteria entering the stomach (bacteriolytic action).

(iii) Provides acid medium which is necessary for the action of hormones.

5. Excretory function

Many substances like toxins, alkaloids and metals are excreted through gastric juice.

The Small Intestine

Small intestine is the part of GI tract extending between the pyloric sphincter of stomach and ileocecal valve, which opens into large intestine. It has a small diameter compared to large intestine. Its functional importance is absorption. Maximum absorption of digested food products takes place in small intestine. It consists of three portions:

1. Proximal part known as duodenum
2. Middle part known as jejunum
3. Distal part known as ileum

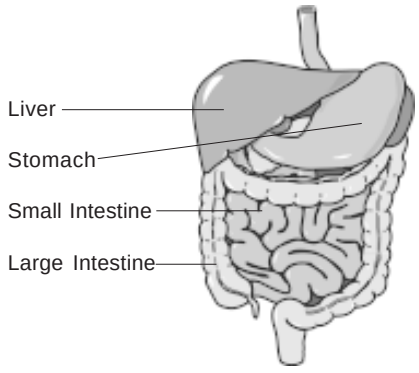


Fig. 7.3: Intestine.

Intestinal villi

The mucous membrane of small intestine is covered by minute projections called **villi.** These are about 1mm in height and half diameter is less than 1mm. These are lined by columnar cells called enterocytes. Each enterocyte gives rise to hair-like projections called microvilli. Both villi and microvilli increase the surface area of mucous membrane.

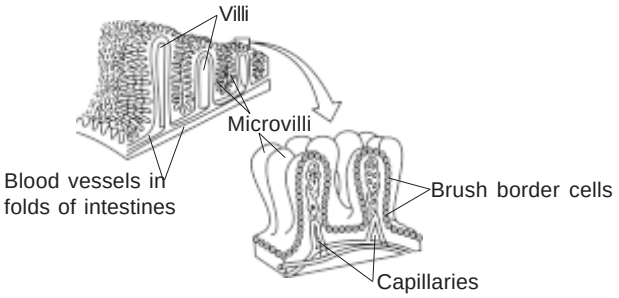


Fig. 7.4: Intestinal villi.

Crypts of Lieberkuhn or Intestinal Glands

These are simple tubular glands of the intestine. The intestinal glands open into lumen of intestine between the villi. These are lined by columnar cells. The lining of each gland is continuous with the epithelial lining of the villi.

Brunner's Glands: These are the first part of duodenum. These contain some mucous glands that penetrate muscularis mucosa and extend up to submucous coat of the intestinal wall. These open into lumen of intestine directly and secrete mucus and traces of enzymes.

Functions Of The Succus Entericus (Secretion from small intestine)

1. **Digestive function:** The enzymes of succus entericus act on the partially digested food and convert it into final digestive products. Some enzymes are secreted by enterocytes of the villi. **Proteolytic enzymes** are peptidases which convert peptides into amino acids. **Amylolytic enzymes** are lactase, sucrase and maltase. These convert the disaccharide into two molecules of monosaccharides. **Lipolytic enzymes** are lipases that convert triglycerides into fatty acids.
2. **Protective function:** The mucus present helps in protection of the intestinal wall from the acid chyme, which enters from stomach, and prevents intestinal ulcer.
3. **Hemopoietic function:** The intrinsic factor of castle, which is present in the intestine, plays an important role in erythropoiesis.
4. **Hydrolytic process:** Intestinal juice helps in all the enzymatic reactions of digestion.

Functions of Small Intestine

1. **Mechanical function:** The mixing movement of small intestine help in the thorough mixing of chyme with the digestive juices like succus entericus, pancreatic juice and bile.

2. **Secretory function:** Small intestine secretes succus entericus, enterokinase and the GI hormones.
3. **Hormonal function:** Small intestine secretes many GI hormones like secretin, cholecystokinin etc. which regulate the movement of GI tract and secretory activities of small intestine and pancreas.
4. **Absorptive functions:** The presence of villi and microvilli increases the surface area of the mucosa that which facilitates the absorptive function of the intestine. Digested food stuffs enter lumen of intestine and then pass through lacteal of villi, cross the mucosa and enter the blood directly or through lymphatics.
5. **Digestive, hemopoietic and hydrolytic function** are associated with small intestine and are performed by the succus entericus—a secretion of small intestine.

Large Intestine

The large intestine is also known as colon. It extends from ileocecal valve upto anus. It consists of seven portions: cecum with appendix, ascending colon, transverse colon, descending colon, sigmoid colon or pelvic colon, rectum and anal canal.

Structure of wall of large intestine

It has four layers. (i) Serous layer formed by peritoneum. (ii) Muscular layer composed of smooth muscles of large intestine is distributed in two layers namely the outer

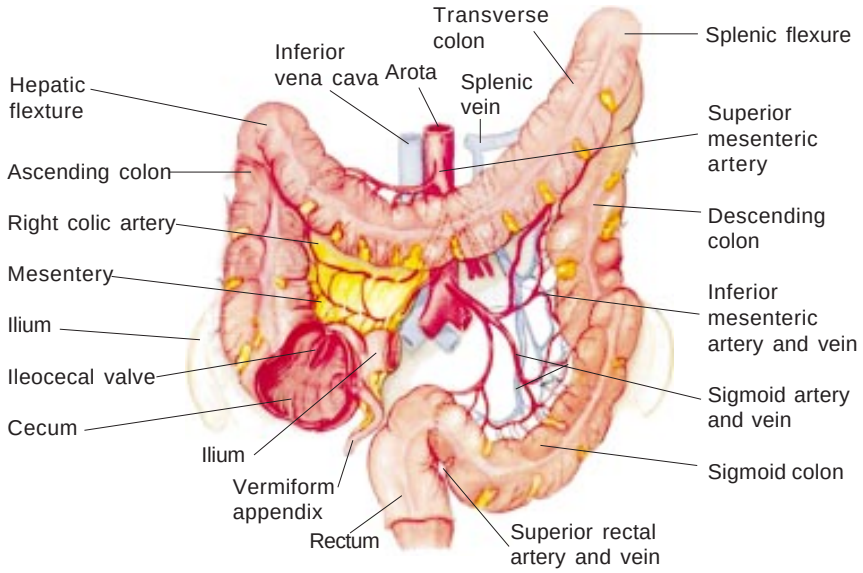


Fig. 7.5: Large Intestine.

longitudinal layer and inner circular layer. (iii) Submucus layer is not well developed in large intestine.(iv) Mucus layer has crypts of liberkuhn present in mucosa of large intestine. Only mucus secreting glands are present in the mucosa of large intestine.

Functions of Large Intestine

1. **Absorptive function:** The large intestine plays role in absorption of various substances like water, electrolytes, organic substances like glucose, alcohol, drugs like anesthetic agents, sedatives and steroids.
2. **Formation of feces:** After the absorption of nutrients, unwanted substances in the large intestine form feces and are excreted out.
3. **Excretory function:** The large intestine excretes heavy metals like mercury, bismuth and arsenic through feces.
4. **Secretory function:** It secretes mucin and inorganic substances like chlorides and bicarbonates.
5. **Synthetic function:** The bacterial flora of LI synthesizes folic acid, Vit. B12 and vit.K and hence contributes erythropoitic activity and blood clotting mechanism.

7.4 MOVEMENTS OF GASTROINTESTINAL TRACT

Mastication: It is the first mechanical process in the GI tract by which the food substances are torn into small particles and crushed or ground into a soft bolus. The significance of mastication are, breakdown of foodstuffs, mixing of saliva with food substances thoroughly, lubrication and moistening of dry food and appreciation of taste of the food. This is controlled by reflux process or carried out voluntarily.

Deglutition: Swallowing of food is known as deglutition which occurs in three stages:

(i) Oral stage when food enters the pharynx from mouth.

(ii) Pharyngeal stage when food enters oesophagus.

(iii) Esophageal stage when food enters stomach from oesophagus.

Physiology of Digestion and Absorption

The small intestines are the primary area of the body for digestion of foodstuffs. Digestion occurs through the action of enzymes. The result of the digestion is the end products. These end products (molecules or particles) are of such size that they can be absorbed through the walls of the small intestines. The end products are then distributed throughout the body by the circulatory systems.

Digestion as a chemical process

a. Digestion is the chemical process that breaks foodstuffs down into their basic constituents. In general, chemical processes are expected to occur at a rate proportional to the temperature. However, in the human body, the temperature is not high enough for the chemical process of digestion to produce a sufficient quantity of the materials needed.

b. Therefore, digestive enzymes are present to maintain the appropriate rates of reaction. Digestive enzymes are catalysts. A catalyst is a substance that improves the rate of a reaction without being consumed itself. Because of digestive enzymes, digestion proceeds at a pace fast enough to provide the materials needed by the body.

c. The majority of digestion in humans takes place in the small intestines. The small intestines are located in the central part of the abdomen, immediately beneath the abdominal wall. In healthy individuals, a flap called the greater omentum is draped over the small intestines (between them and the anterior abdominal wall). The greater omentum has a great deal of fat for insulation. It is richly supplied with blood vessels for heat. Some might compare the greater omentum to an "electric blanket" for the small intestines.

Foodstuff	Enzyme Class	End Products
Carbohydrates	Amylases	Simple Sugars
Lipids	Lipases	Fatty Acids and Glycerol
Proteins	Proteases	Amino Acids

Table. Foodstuffs, enzyme classes, and end-products of digestion.

Digestive enzymes

a. The digestive process begins in the oral cavity. The saliva contains enzymes which initiate the digestion of complex carbohydrates.

b. In the stomach, the gastric glands produce enzymes that initiate the digestion of proteins.

c. In the small intestines, there are digestive enzymes for all three classes of foodstuffs—carbohydrates, lipids, and proteins. Enzymes for completing the digestion of these three classes are found in the fluids produced by the pancreas and glands in the mucosa of the small intestines. Moreover, there is a fluid called bile that is produced by the liver and stored in the gallbladder for release into the small intestines. Bile helps in the digestion of lipids.

d. The presence or absence of certain enzymes is genetically determined. Therefore, some individuals may have difficulty digesting certain foods.

Absorption

The end products of digestion are absorbed primarily through the walls of the small intestines.

a. **Surface Area:** The amount of absorption is proportional to the surface area of the walls, which contact the contents. Two anatomical specializations serve to increase this surface area:

   (1) There are permanent circular folds in the mucosal lining of the small intestines.

   (2) The entire inner surface of the mucosa is covered with villi. Villi are minute, fingerlike processes that extend into the lumen (cavity) of the small intestines.

b. **Capillaries**: The simple sugars and amino acids are absorbed into the blood capillaries. Most of the fatty acids and glycerol are absorbed into the lymphatic capillaries.

Pancreas

The **pancreas** is a gland organ in the digestive and endocrine system of vertebrates. It is both exocrine (secreting pancreatic juice containing digestive enzymes) and endocrine (producing several important hormones, including insulin, glucagon, and somatostatin).

Pancreatic juice is a juice produced by the pancreas. It contains a variety of enzymes including trypsinogen, chymotrypsinogen, elastase, carboxypeptidase, pancreatic lipase, and amylase.

Pancreatic juice is alkaline in nature due to the high concentration of bicarbonate ions. This is useful in neutralizing the acidic gastric acid, allowing for effective enzymic action.

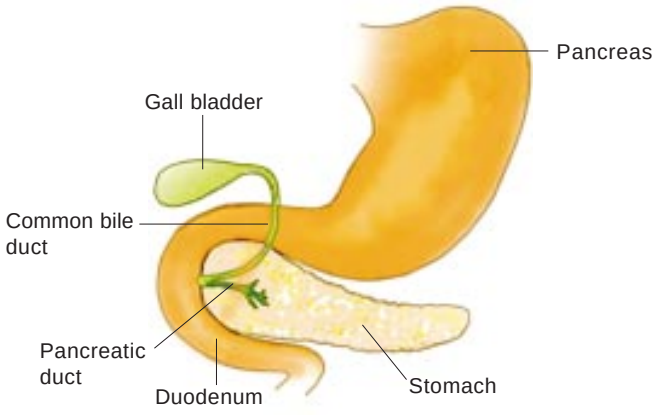


Fig. 7.6: Pancreas.

Pancreatic juice secretion is regulated by the hormones, secretin and cholecystokinin, which are produced by the walls of the duodenum upon detection of acid food, proteins and fats. Pancreatic secretion consists of an aqueous bicarbonate component from the duct cells and enzymatic component from the acinar cells.

Functions of Pancreatic juices

The secretions of the pancreas, called pancreatic juice, include various enzymes, like pancreatic amylase (digestion of starch), trypsin, carboxypeptidase, and chymotrypsin (proteases), as well as pancreatic lipase (digestion of fats). Sodium bicarbonate is also produced, making the pancreatic juice alkaline. An alkaline solution neutralizes the HCl in the chyme and provides an optimal environment for the action of these enzymes.

Pancreatic juice is produced in clusters of exocrine cells called acini. The remaining cells in the pancreas (about 1 percent of the total) also form clusters (islets of Langerhans). These are the endocrine cells that produce the hormones insulin, glucagon, somatostatin, and pancreatic polypeptide.

Pancreatic juice collects in small ducts that merge to form two large ducts. The main pancreatic duct (duct of Wirsung) exits the pancreas and merges with the common bile duct from the liver and gallbladder. This combined duct, called the hepatopancreatic ampulla (ampulla of Vater), then enters the duodenum. A smaller, second duct that exits the pancreas, the accessory pancreatic duct (duct of Santorini), joins the duodenum directly.

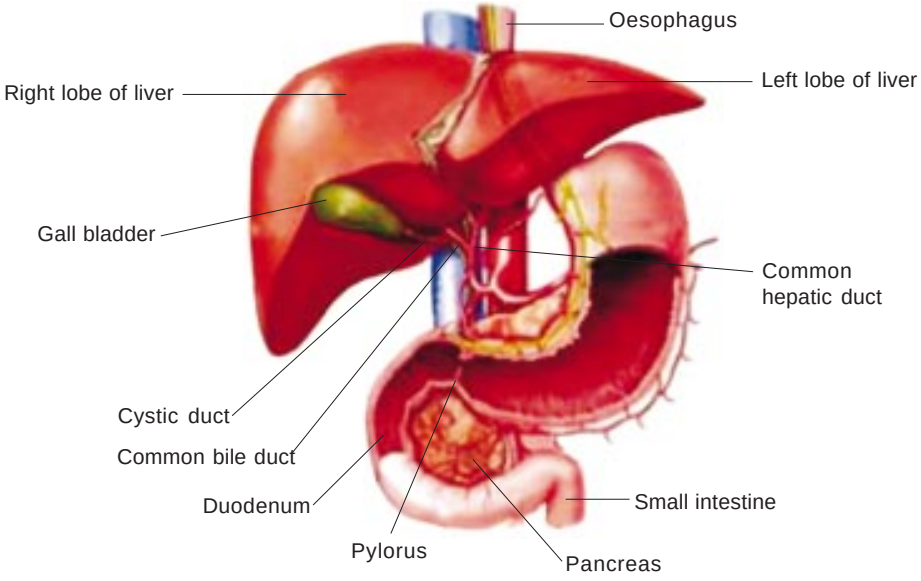
Liver and Gallbladder

The digestive function of the liver is to produce bile, which is then delivered to the duodenum to emulsify fats. Emulsification is the breaking up of fat globules into smaller fat droplets, increasing the surface area upon which fat-digesting enzymes (lipases) can operate. Since bile does not chemically change anything, it is not an enzyme. Bile is also alkaline, thus serves to help neutralize the Hcl in the chyme.

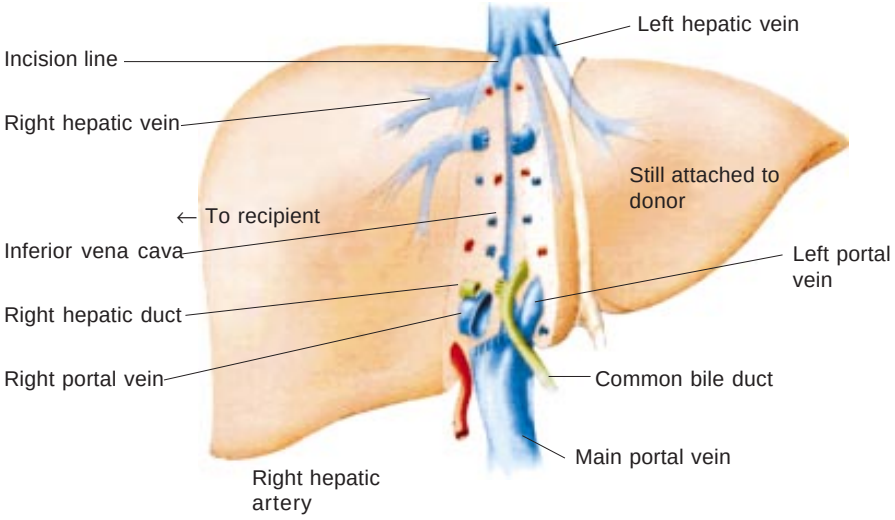
Bile consists of bile salts, bile pigments, phospholipids (including lecithin), cholesterol, and various ions. The primary bile pigment, bilirubin, is an end product of the breakdown of hemoglobin from expended red blood cells. Although some of the bile is lost in the feces (bilirubin gives feces their brown color), much of it is reabsorbed by the small intestine and returned to the liver via the hepatic portal vein.

The liver performs numerous metabolic functions:

1. Production of bile.



(a)



(b)

Fig. 7.7:

2. Blood glucose is regulated. When blood glucose is high, the liver converts glucose to glycogen (glycogenesis) and stores the glycogen. When blood glucose is low, glycogen is broken down (glycogenolysis), and glucose is released into the blood.

3. Proteins (including plasma proteins) and certain amino acids are synthesized.
4. Ammonia (which is toxic) is converted to urea (less toxic) for elimination by the kidneys.
5. Bacteria and expended red and white blood cells are broken down. From the red blood cells, Fe and globin are recycled, and bilirubin is secreted in the bile.
6. Vitamins (A, D, and B_{12}) and minerals (including Fe from expended red blood cells) are stored.
7. Toxic substances (drugs, poisons) and hormones are broken down.

The liver is composed of numerous functions units called lobules. Within each lobule, epithelial cells called hepatocytes are arranged in layers that radiate out from a central vein. Hepatic sinusoids are spaces that lie between groups of layers, while smaller channels called bile canaliculi separate other layers. Each of (usually) six corners of the lobule is occupied by three vessels: one bile duct and two blood vessels (a portal triad). The blood vessels are branches from the hepatic artery (carrying oxygenated blood) and from the hepatic portal vein (carrying deoxygenated but nutrient-rich blood from the small intestine).

Blood enters the liver through the hepatic artery and hepatic portal vein and is distributed to lobules. Blood flows into each lobule by passing through the hepatic sinusoid and collecting in the central vein. The central veins of all the lobules merge and exit the liver through the hepatic vein (not the hepatic portal vein).

Within the sinusoids, phagocytes called Kupffer cells (stellate reticuloendothelial cells) destroy bacteria and break down expended red and white blood cells and other debris. Hepatocytes that border the sinusoids also screen the incoming blood. They remove various substances from the blood, including oxygen, nutrients, toxins, and waste materials. From these substances, they produce bile, which they secrete into the bile canaliculi, which empties into bile ducts. Bile ducts from the various lobules merge and exit the liver as a single common hepatic duct. The common hepatic duct merges with the cystic duct from the gallbladder to form the common bile duct, which, in turn, merges with the pancreatic duct to form the hepatopancreatic ampulla. This last duct delivers the bile to the duodenum.

The gallbladder stores excess bile. When food is in the duodenum, bile flows readily from the liver and gallbladder into the duodenum. When the duodenum is empty, a sphincter muscle (sphincter of Oddi) closes the hepatopancreatic ampulla, and bile backs up and fills the gallbladder.

7.5 THE BASIC ENERGY REQUIREMENTS OF BODY

Energy is supplied by three types of compounds—carbohydrates (CHO), fats and proteins, which contribute 42 % (CHO), 41 % (fats) and 17 % of the total energy. The main source of energy in short or medium term exercise is CHO (as glycogen). This is gradually replaced by lipid, as the period of muscular exercise becomes longer. Proteins are mainly used as an energy source during prolonged exercise. The oxidation of amino acids, mainly branched chain amino acids, can provide 10 - 15 % of the total energy requirement.

The Energy Production and Protein metabolism

The concept of nitrogen balance

The sources of macronutrient energy in the food are carbohydrates, lipids and proteins. The body energy reserves are provided by body fats and proteins, especially muscle proteins. These proteins also have an important functional role and are constantly renewed at the rate of about 250 - 300 g/day. This turnover is a major factor in the body capacity to adapt to its environment.

After a meal, insulin is the dominant influence on postprandial metabolism, stimulating the use of absorbed food substrates. These are used either for energy production or to produce reserves in the form of protein, glycogen, or triglycerides. The main source of energy in extra-hepatic tissues during the prandial and post-prandial phases is glucose. Ingested proteins are digested to release amino acids, which are absorbed and pass into the portal blood. They are carried to the liver, where they are taken up. The influence of insulin results in increased synthesis of body proteins, especially in the liver and muscle.

The liver is a major site of amino acid uptake and metabolism. Amino acids can be converted to other amino acids, metabolized in cells to form glucose, lipids or ketones, or oxidized, depending on the body's requirements.The circulating branched chain amino acids are actively taken up by muscle, and to a lesser extent by the heart, the brain and the kidney.

In A Fasting Stage

The body switches to use the energy stored in its reserves in the post-absorptive and fasting stages. The blood sugar level falls once the dietary glucose has been absorbed and used, and this shuts off insulin secretion.

Glycogen is hydrolyzed in the liver to maintain the blood glucose concentration. Lipolysis is also activated in adipose tissue, while protein hydrolysis restarts in the liver and muscle and the liberated amino acids are also used to produce glucose by gluconeogenesis.

There is an active proteolysis in the muscles of individuals in the post-absorptive and fasting stages. The branched chain amino acids are preferentially desaminated by transamination to produce alanine and glutamine.

Most of the glutamine is taken up by the intestine, liver and kidney. The intestine is the main user of glutamine and releases alanine, serine and smaller quantities of citrulline. The amino acids taken up by the liver are used for gluconeogenesis.

What are the implications?

The concept of nitrogen balance: It is a very simple tool. It is balanced when the same amount of nitrogen (proteins) goes in the body than the quantity of nitrogen goes out. An athlete does not want to be in a negative balance because that would mean he is using his mass muscle as an energy reserve, thus depleting some power from the muscle.

The nitrogen balance can become negative when the glycogen reserve is very low. Then muscle proteolysis will release mainly glutamine and alanine from branched chain amino-acids (BCAA) to produce glucose in the liver. Consequently the athlete needs to have enough energy from other sources like carbohydrates to avoid using his muscle as an energy storage. He can also increase his dietary intake of branched amino acid. There are many different situations between different periods (heavy training, post competition, caloric restriction for weight control…) and various sports (biking, swimming, running…). The protein requirement will therefore vary from one person to another. Sedentary workers need only 0.8 g of high quality protein per kg body weight per day. Endurance athletes (marathon runners, road race cyclists, triathlon athletes) need 1.5-2 g/kg/day, while sprint athletes (track cyclists, bodybuilders,…) need 1.3-1.6 g/kg/day ; those practising weight category sports (judo, boxing) need 1.5-2 g/kg/day, and those athletes doing strength sports in which muscle mass is developed need 1.5-2 g/kg/day. These protein intakes are designed to keep the body at least in nitrogen balance, or even to give a positive balance with increased muscle mass for certain athletes or those requiring it.

It is generally acknowledged that a period of heavy training and/or mass building will require a positive nitrogen balance with two to sometimes three times the recommended intake. Please note that some of this intake is used to repair the muscle, which can suffer from tissue lesions after heavy exercise.

Because of this high intake of protein, it is absolutely necessary to eat the proteins with the best biological value. Otherwise, to obtain the same assimilation by the body, you would have to increase the overall quantity of ingested protein and it could be a risk for major metabolic functions such as kidney for example, that would have to "process" an overload of materials.

CHAPTER 8

Excretory System

"Excretion is a biological maceration
Accomplishes urination with rhythmic saltation
Functions in secretion and reabsorption
Promotes man to be in salubrious condition"

8.1 INTRODUCTION

The excretory system is the system in an organism's body that performs the function of excretion, the process of discharging wastes. It is responsible for the elimination of wastes produced by homeostasis. There are several parts of the body that are responsible for this process, such as the sweat glands, the liver, the lungs, and the kidneys. It removes wastes of the organism, balancing and regulating the chemical composition of its body fluids. The excretory system eliminates excretory products from the body, collects water and filters body fluids. Its parts include anything that aids in removing wastes and unneeded substances. Without a properly functioning excretory system, the accumulated wastes could cause damage to the body.

8.2 HUMAN EXCRETORY SYSTEM

The human excretory system functions to remove waste from the human body. This system consists of specialized structures and capillary networks that assist in the excretory process. The human excretory system includes the kidney and its functional unit, the nephron. The excretory activity of the kidney is modulated by specialized hormones that regulate the amount of absorption within the nephron.

Kidneys

The **kidneys** are complex organs that have numerous biological roles. Their primary role is to maintain the homeostatic balance of bodily fluids by filtering and secreting metabolites (such as urea) and minerals from the blood and excreting them, along with water, as urine. Since the kidneys are poised to sense plasma concentrations of compounds such as sodium, potassium, hydrogen ion, oxygen, and glucose, they are important regulators of blood pressure, glucose metabolism, and erythropoeisis (the process by which red blood cells (erythrocytes) are produced). The medical field that studies the kidneys and diseases of the kidney is called nephrology. The prefix *nephro-* meaning kidney is from the Ancient Greek word *nephros* the adjective *renal* meaning related to the kidney is from Latin renes, meaning kidneys.

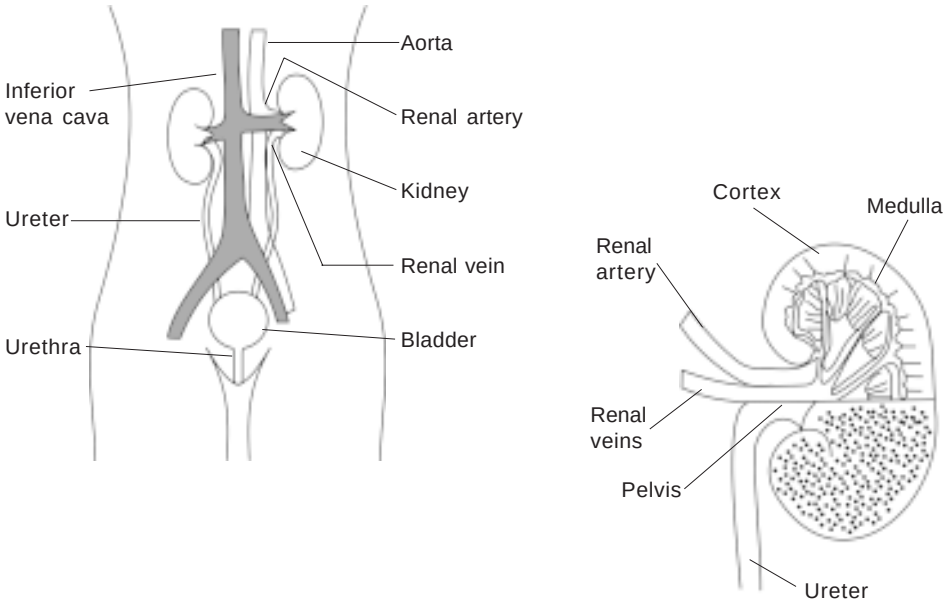
In humans, the kidneys are located in the posterior part of the abdomen. There is one on each side of the spine; the right kidney sits just below the liver, the left below the diaphragm and adjacent to the spleen. Above each kidney is an adrenal gland (also called the *suprarenal gland*). The asymmetry within the abdominal cavity caused by the liver results in the right kidney being slightly lower than the left one, while the left kidney is located slightly more medial.

Fig. 8.1 Details of the human excretory system. Position and allied structures of the kidneys (a). A cross section of the kidney showing the two major portions. (b) Details of the nephron, the functional unit of the kidney (right).

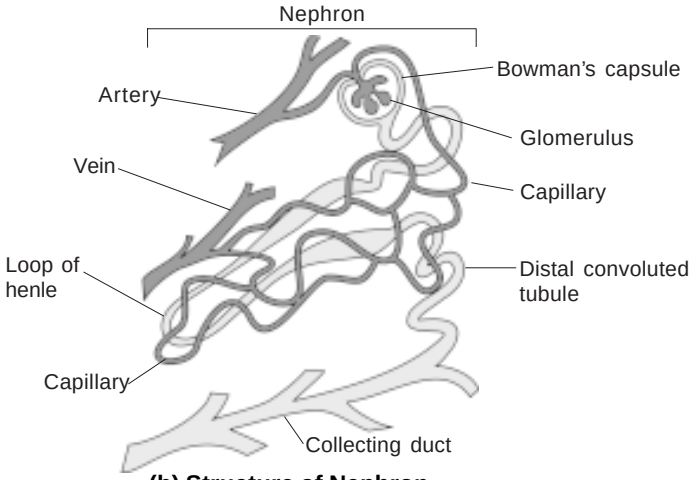
The kidneys are retroperitoneal and range from 9 to 13 cm in diameter; the left slightly larger than the right. They are approximately at the vertebral level T12 to L3. The upper parts of the kidneys are partially protected by the eleventh and twelfth ribs, and each whole kidney is surrounded by two layers of fat (the perirenal and pararenal fat) which help to cushion it. Congenital absence of one or both kidneys, known as unilateral or bilateral renal agenesis, can occur.

The Nephron

A **nephron** (from Greek (nephros) meaning “kidney”) is the basic structural and functional unit of the kidney. Its chief function is to regulate the concentration of water and soluble substances like sodium salts by filtering the blood, reabsorbing what is needed and excreting the rest as urine. A nephron eliminates wastes from the body, regulates blood volume and pressure, controls levels of electrolytes and metabolites, and regulates blood pH. Its functions are vital to life and are regulated by the endocrine system by hormones such as antidiuretic hormone, aldosterone, and parathyroid hormone.



(a) Two major portions of kidney



(b) Structure of Nephron

Fig. 8.1: (a) Two major portions of kidney (b) Structure of Nephron.

Types of nephrons

Two general classes of nephrons are cortical nephrons and juxtamedullary nephrons, both of which are classified according to the location of their associated renal corpuscle. Cortical nephrons have their renal corpuscle in the superficial renal cortex, while the renal corpuscles of juxtamedullary nephrons are located near the renal medulla. The nomenclature for cortical nephrons varies, with some sources distinguishing between

superficial cortical nephrons and *midcortical nephrons*; other sources simply call all non-juxtamedullary nephrons *superficial nephrons*.

Functionally, cortical and juxtamedullary nephrons have distinct roles. Cortical nephrons (85% of all nephrons) mainly perform excretory and regulatory functions, while juxtamedullary nephrons (15% of nephrons) concentrate and dilute urine.

Anatomy

Each nephron is composed of an initial filtering component (the "renal corpuscle") and a tubule specialized for reabsorption and secretion (the "renal tubule"). The renal corpuscle filters out large solutes from the blood, delivering water and small solutes to the renal tubule for modification.

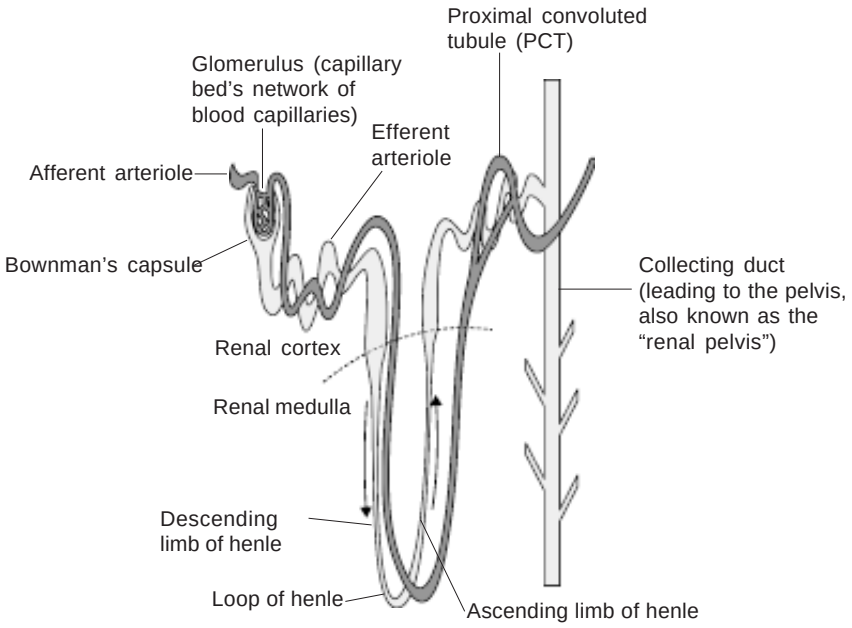

Proximal convoluted tubule (PCT)
Glomerulus (capillary bed's network of blood capillaries)
Efferent arteriole
Afferent arteriole
Bownman's capsule
Collecting duct (leading to the pelvis, also known as the "renal pelvis")
Renal cortex
Renal medulla
Descending limb of henle
Loop of henle
Ascending limb of henle

Fig. 8.2:

Renal corpuscle

Composed of a glomerulus and Bowman's capsule, the renal corpuscle (or *Malpighian corpuscle*) is the beginning of the nephron. It is the nephron's initial filtering component.

Glomerulus: The glomerulus is a capillary tuft that receives its blood supply from an afferent arteriole of the renal circulation. The glomerular blood pressure provides the driving force for water and solutes to be filtered out of the blood and into the space made by Bowman's capsule. The remainder of the blood (only approximately 1/5 of

all plasma passing through the kidney is filtered through the glomerular wall into Bowman's capsule) passes into the narrower efferent arteriole. It then moves into the vasa recta, which collect capillaries intertwined with the convoluted tubules through the interstitial space, and through which the reabsorbed substances will also enter. This then combines with efferent venules from other nephrons into the renal vein, and rejoins the main bloodstream.

Bowman's capsule

Bowman's capsule (also called the glomerular capsule) surrounds the glomerulus and is composed of a visceral inner layer and a parietal outer layer, both formed by simple squamous epithelial cells. Fluids from blood in the glomerulus are collected in the Bowman's capsule (i.e., glomerular filtrate) and further processed along the nephron to form urine.

Renal tubule

The **kidney tubule**, also **renal tubule**, is the portion of the **nephron** of the kidney containing the tubular fluid filtered through the glomerulus. After passing the tubule, the filtrate continues to the collecting duct system.

The components of the kidney tubule are:

- Proximal tubule
- Loop of Henle
  - Descending limb of loop of Henle
  - Ascending limb of loop of Henle
    - i) Thin ascending limb of loop of Henle
    - ii) Thick ascending limb of loop of Henle
- Distal convoluted tubule

Formation of Urine

The nephron makes urine by

- filtering the blood of its small molecules and ions and then
- reclaiming the needed amounts of useful materials.
- Surplus or waste molecules and ions are left to flow out as urine.

In 24 hours the kidneys reclaim

- ~1,300 g of NaCl
- ~400 g $NaHCO_3$

- ~180 g glucose
- almost all of the 180 liters of water that entered the tubules.

The steps:

- Blood enters the glomerulus under pressure.
- This causes water, small molecules (but not macromolecules like proteins) and ions to filter through the capillary walls into the **Bowman's capsule**. This fluid is called **nephric filtrate**. As the table shows, it is simply blood plasma minus almost all of the plasma proteins. Essentially, it is no different from interstitial fluid.

Table 8.1: Composition of plasma, nephric filtrate, and urine (each in g/100 ml of fluid). These are representative values. The values for salts are especially variable, depending on salt and water intake.

Component	Plasma	Nephric Filtrate	Urine	Concen-tration	% Reclaimed
Urea	0.03	0.03	1.8	60X	50%
Uric acid	0.004	0.004	0.05	12X	91%
Glucose	0.10	0.10	None	–	100%
Amino acids	0.05	0.05	None	–	100%
Total inorganic salts	0.9	0.9	<0.9–3.6	<1–4X	99.5%
Proteins and other macromolecules	8.0	None	None	–	–

- Nephric filtrate collects within the Bowman's capsule and then flows into the **proximal tubule**.
- Here all of the **glucose**, and **amino acids**, >90% of the uric acid, and ~60% of inorganic **salts** are reabsorbed by active transport.
  - The active transport of Na^+ out of the **proximal tubule** is controlled by angiotensin II.
  - The active transport of phosphate (PO_4^{3-}) is regulated (suppressed by) the parathyroid hormone.
- As these solutes are removed from the nephric filtrate, a large volume of the water follows them by osmosis (80–85% of the 180 liters deposited in the Bowman's capsules in 24 hours).
- As the fluid flows into the descending segment of the **loop of Henle**, water continues to leave by osmosis because the interstitial fluid is very hypertonic.

This is caused by the active transport of Na^+ out of the tubular fluid as it moves up the ascending segment of the loop of Henle.

- In the **distal tubules**, more sodium is reclaimed by active transport, and still more water follows by osmosis.
- Final adjustment of the sodium and water content of the body occurs in the **collecting tubules**.

Sodium

Although 97% of the sodium has already been removed, it is the last 3% that determines the final balance of sodium — and hence water content and blood pressure — in the body. The reabsorption of sodium in the **distal tubule** and the collecting tubules is closely regulated, chiefly by the action of the hormone **aldosterone**.

Water

- The hypertonic interstitial fluid surrounding the collecting tubules provides a high osmotic pressure for the removal of water.
- Transmembrane channels made of proteins called **aquaporins** are inserted in the plasma membrane, greatly increasing its permeability to water. (When open, an aquaporin channel allows 3 billion molecules of water to pass through each second.)
- Insertion of aquaporin-2 channels requires signaling by the **antidiuretic hormone** (**ADH**; also known as **arginine vasopressin** or **AVP**).
  - ADH binds to receptors (called **V2 receptors**) on the basolateral surface of the cells of the collecting tubules.
  - Binding of the hormone triggers a rising level of **cAMP** within the cell.
  - This **"second messenger"** initiates a chain of events culminating in the insertion of **aquaporin-2** channels in the apical surface of the cell.

The release of **ADH** (from the posterior lobe of the pituitary gland) is regulated by the osmotic pressure of the blood.

- Anything that dehydrates the body, such as perspiring heavily,
  - increases the osmotic pressure of the blood;
  - turns on the **ADH → V2 receptors → aquaporin-2** pathway.

The result:

  - As little as 0.5 liter/day of urine may remain of the original 180 liters/day of nephric filtrate.

  - The concentration of salts in the urine can be as much as four times that of the blood. (But not high enough to enable humans to benefit from drinking sea water, which is saltier still.)

- If the blood should become too dilute (as would occur after drinking a large amount of water),
  - **ADH** secretion is **inhibited**.
  - The aquaporin-2 channels are taken back into the cell by endocytosis.
  - The result: a large volume of watery urine is formed (with a salt concentration as little as one-fourth of that of the blood).

Diabetes insipidus

This disorder is characterized by:

- excretion of large amounts of a watery urine (as much as 30 liters — about 8 gallons — each day!)
- unremitting thirst.

It can have several causes:

- Insufficient secretion of **ADH**.
- Inheritance of two mutant genes for the **ADH receptor** (V2).
- Inheritance of two mutant genes for **aquaporin-2**.

Liddle's Syndrome

The most obvious effect of this rare, inherited disorder is extremely high blood pressure (hypertension). It is caused by a single mutant allele (therefore the syndrome is inherited as a dominant trait) encoding the aldosterone-activated **sodium channel** in the **collecting tubules**. The defective channel is always "on" so too much Na^+ is reabsorbed and too little is excreted. The resulting elevated osmotic pressure of the blood produces hypertension.

Tubular Secretion

Although urine formation occurs primarily by the filtration-reabsorption mechanism described above, an auxiliary mechanism, called tubular secretion, is also involved.

The cells of the tubules remove certain molecules and ions from the blood and deposit these into the fluid within the tubules. For example, both hydrogen ions (H^+) and potassium ions (K^+) are secreted directly into the fluid within the distal and collecting tubules. In each case the secretion is coupled to the ion-for-ion uptake of sodium ions (Na^+).

Tubular secretion of H^+ is important in maintaining control of the pH of the blood.

- When the pH of the blood starts to drop, more hydrogen ions are secreted.
- If the blood should become too alkaline, secretion of H^+ is reduced.
- In maintaining the pH of the blood within its normal limits of 7.3–7.4, the kidney can produce a urine with a pH as low as 4.5 or as high as 8.5.

The Kidney and Homeostasis

While we think of the kidney as an organ of excretion, it is more than that. It does remove wastes, but it also removes normal components of the blood that are present in greater-than-normal concentrations. When excess water, sodium ions, calcium ions, potassium ions, and so on are present, the excess quickly passes out in the urine. On the other hand, the kidneys step up their reclamation of these same substances when they are present in the blood in less-than-normal amounts. Thus the kidney continuously regulates the chemical composition of the blood within narrow limits. The kidney is one of the major homeostatic devices of the body.

Hormones of the Kidneys

The human kidney is also an endocrine gland secreting two hormones:

- **Erythropoietin** (**EPO**)
- **Calcitriol** ($1,25[OH]_2$ Vitamin D_3), the active form of vitamin D

8.3 SKIN

Skin forms the largest organ of the body, accounting for about 16 per cent of a person's weight. It performs many vital roles as both a barrier and a regulating influence between the outside world and the controlled environment within our bodies.

Internal body temperature (core temperature) is controlled through several processes, including the combined actions of sweat production and the rate of blood flowing through the network of blood vessels within the skin.

In very cold conditions skin blood flow drops very low, retaining heat in the centre of the body and preserving the flow of warm blood to the vital organs within the chest and abdomen and to the brain.

The skin and the fat layer beneath it also act as good insulators. In a hot environment or when generating heat from muscle activity skin vessels open up, potentially increasing skin blood flow to as much as a third of the total output of blood from the heart. Thus the skin turns into a heat radiator. The evaporation of sweat from the skin greatly increases the rate at which heat can be lost from the body.

The physical toughness of the skin prevents the ingress of harmful chemicals and invading organisms such as bacteria and viruses. It also provides resistance to shocks for the more sensitive tissues underneath. At the same time, however, skin needs to be supple and be able to stretch to accommodate movement.

Sweat Glands

The skin contains two different groups of **sweat glands**: apocrine sweat glands and merocrine sweat glands. Both gland types contain **myoepithelial cells** (from Latin *myo*-, "muscle"), specialized epithelial cells located between the gland cells and the underlying basal lamina. Myoepithelial cell contractions squeeze the gland and discharge the accumulated secretions. The secretory activities of the gland cells and the contractions of myoepithelial cells are controlled by both the autonomic nervous system and the circulating hormones.

Additionally, ceruminous glands, which produce ear wax, and mammary glands, which produce milk, are frequently considered to be modified sweat glands.

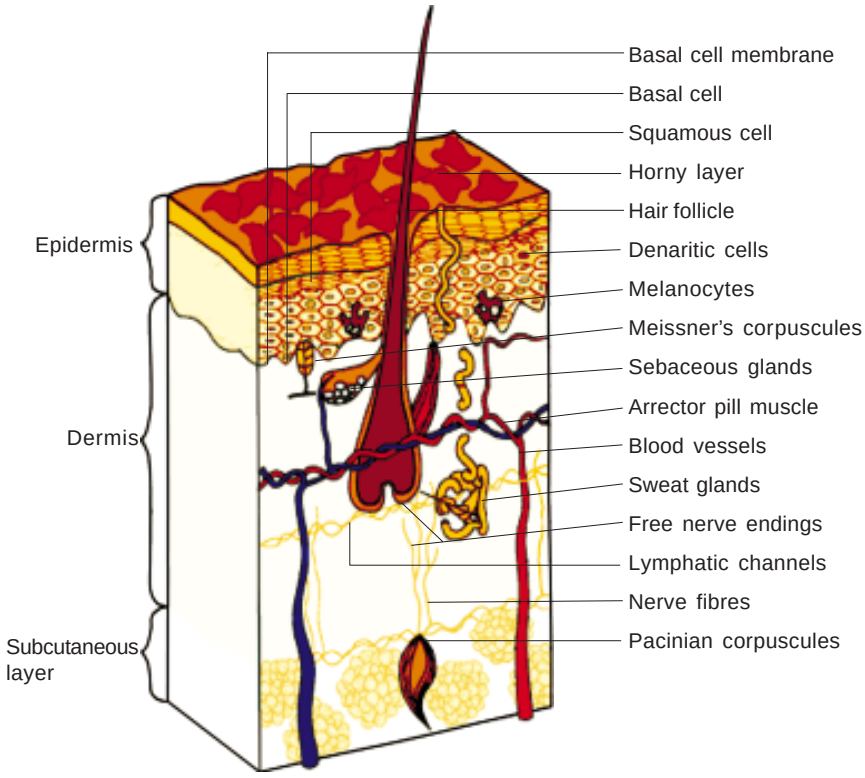


Fig. 8.3: Structure of skin showing the presence of various glands.

Apocrine sweat glands

Sweat glands that release their secretions into hair follicles in the axillae (armpits), around the nipples (*areolae*), and in the groin are termed apocrine sweat glands. The name *apocrine* was originally chosen because it was thought that the gland cells used an apocrine method of secretion. Although it is now known that their secretory products are produced through merocrine secretion, the name has not changed. Apocrine sweat glands are coiled tubular glands that produce a viscous, cloudy, and potentially odorous secretion. They begin secreting at puberty; the sweat produced may be acted upon by bacteria, causing a noticeable odor. Apocrine gland secretions may also contain *pheromones*, chemicals that communicate information to other individuals at a subconscious level. The apocrine secretions of mature women have been shown to alter the menstrual timing of other women. The significance of these pheromones, and the role of apocrine secretions in males, remains unknown.

Merocrine sweat glands

A type of sweat gland that is far more numerous and widely distributed than apocrine sweat glands is the merocrine sweat glands, also known as *eccrine sweat glands.* The adult integument contains around 3 million merocrine glands. They are smaller than apocrine sweat glands, and they do not extend as far into the dermis. Palms and soles have the highest numbers; estimates are that the palm of the hand has about 500 glands per square centimeter (3000 glands per square inch). Merocrine sweat glands are coiled tubular glands that discharge their secretions directly onto the surface of the skin.

The clear secretion produced by merocrine glands is termed **sweat**, or **sensible perspiration**. Sweat is mostly water (99 percent), but it does contain some electrolytes (chiefly sodium chloride), metabolites, and waste products. The presence of sodium chloride gives sweat a salty taste.

Merocrine glands have three primary functions

- *Thermoregulation*. Sweat cools the surface of the skin and reduces body temperature. This cooling is the primary function of sensible perspiration, and the degree of secretory activity is regulated by neural and hormonal mechanisms. When all of the merocrine sweat glands are working at maximum, the rate of perspiration may exceed a gallon per hour[f] and dangerous fluid and electrolyte losses can occur. For this reason, athletes in endurance sports must pause frequently to drink fluids.
- *Excretion*. Merocrine sweat gland secretion can also provide a significant excretory route for water and electrolytes, as well as for a number of prescription and nonprescription drugs.
- *Protection.* Merocrine sweat gland secretion provides protection from environmental hazards by diluting harmful chemicals and discouraging growth of microorganisms.

Control of Glandular Secretions

Sebaceous glands and apocrine sweat glands can be turned on or off by the autonomic nervous system, but no regional control is possible, meaning that when one sebaceous gland is activated, so are all the other sebaceous glands in the body. Merocrine sweat glands are much more precisely controlled, and the amount of secretion and the area of the body involved can be varied independently. For example, when you are nervously awaiting an exam, your palms may begin to sweat.

8.4 AMMONOTELISM, UREOTELISM AND URICOTELISM

Nitrogen is a major constituent of amino acids and proteins. Generally, animals receive excess of amino acids through their diet. The excess of amino acid is catabolized either for release of energy or is used for the synthesis of glycogen and fat. When proteins, amino acids or nucleic acids are catabolized, 3-nitrogen-containing predominant excretory end-products are formed—**ammonia**, **urea** and **uric acid**.

(A) Ammonotelism: Animals that excrete excess nitrogen in the form of ammonia (NH_3) (the end product of protein metabolism) are called ammonotelic. Ammonia diffuses through the cell membrane extremely fast because of its high water solubility and small molecular size. Therefore, prompt excretion of ammonia occurs in aquatic animals (aquatic invertebrates, fishes, larvae, permanently aquatic amphibia). The route of ammonia diffusion in these animals is through skin, gills or kidneys.

(B) Ureotelism: Animals that excrete excess nitrogen in the form of urea are ureotelic. Terrestrial animals cannot use water freely for excretion (because of less availability in the environment), so ammonia is converted into a less toxic and easily soluble product, urea. In mammals and semi-terrestrial adult amphibians, urea is a major nitrogenous excretory product, therefore these animals are called ureotelic.

(C) Uricotelism: Animals that excrete a major portion of nitrogenous waste in the form of semi-solid or solid uric acid are called **uricotelic** animals (e.g., birds, lizards, snakes, terrestrial insects, snails.) In these animals ammonia is converted into less toxic, relatively insoluble uric acid, which can be excreted with a relatively small amount of water. Arachnids (e.g. spiders, scorpions, etc.) excrete mostly **guanine** and hence are said to be **guanotelic**. The above terms apply to the predominant form of excretory product, but do not exclude the excretion of other forms in minor quantities.

Parts of Urinary System

After the body oxidizes nutrient substances, it must deal with excretion (the elimination of metabolic waste products) to prevent their accumulation and potential poisoning.

Table 8.2: Advantages and disadvantages of nitrogenous wastes in relation to habitat.

Waste	Advantages	Disadvantages	Habitat	Excreted by
Ammonia	Produced with little energy	Toxic in conc. solution Must be excerted in lot of water	Water	Marine and fresh water invertebrates, bonyfish amphibian larvae, crocodiles
Urea	Less toxic than ammonia Less water needed to excrete it.	Requires little more energy to produce it.	Land, sea	Adult amphibians, turtles, mammals and bonyfishes.
Uric acid	Very little water is excreted with it	Requires considereable produce it.	Land	Reptiles, birds, insects, land gastropods.
Guanine	Relatively non-toxic Less water is excreted	More energy needed	Arid Habitat (Land)	Scorpions spiders.

The kidneys are essential to the body's excretory needs. They constantly filter the blood, and selectively reabsorb vital constituents for conservation. Concentrated waste products and some remaining water form urine. The kidneys are also key to the homeostatic regulation of blood volume and pressure, ion concentration, pH, and red blood cell production.

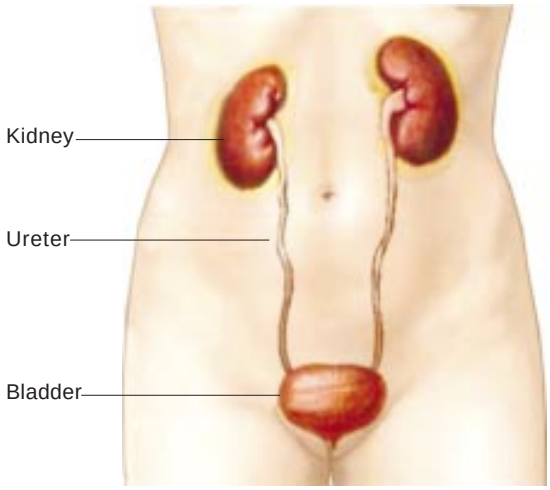


Fig. 8.4: Urinary system.

Glossary

A

Abdomen The area between the diaphragm and pelvis

Abdominal Cavity Superior portion of the abdominopelvic cavity that contains the stomach, spleen, liver, gall bladder, most of the small intestine and part of the large intestine

Abduction Movement away from the midline of the body

Abortion The premature loss or removal of the embryo or nonviable fetus

Abscess A localized collection of pus and liquefied tissue in cavity.

Absorption Intake of fluids or other substances by cells of the skin on mucous membrane.

Accommodation An increase in the curvature of the lens of the eye to adjust for near vision.

Acetylcholine A neuro transmitter liberated by many peripheral nervous system neurons and some central nervous system neurons.

Acid A proton donor or substance that dissociates into hydrogen ions and anions.

Acidosis A condition in which blood pH is below 7.35 also known as academia.

Acoustic Pertaining to sound or the sense of hearing

AIDS Acquired Immuno deficiency syndrome A fatal disease caused by Human immuno deficiency virus (HIV).

Acrosome A lysosome like organelle in the head of a sperm cell containing enzymes that facilitate the penetration of sperm cell into secondary oocyte.

Actin A contractile protein that is part of thin filaments in muscle fibers.

Action potential An electrical signal that propagates along the membrane of a neuron or a muscle fiber.

Activation Energy The minimal amount of energy required for a chemical reaction to occur.

ATP The main energy currency in living cells.

Adenylate cyclase An enzyme that converts ATP into cyclic AMP.

Adepocyte Fat cell.

Adepose Tissue composed of adepocytes specialized for tryglyceroid storage and present in the form of soft pads between various organs for support, protection and insulation.

Adrenal cortex The outer portion of an adrenal gland, divided into three zones; the zona glomerulosa secretes mineralocorticoids, the zona fasciculate secretes glucocorticoids and zona reticularis secretes androgens.

Adeventitia The outermost covering of a structure or organ.

Afferent arteriole A blood vessel of a kidney that divides into the capillary network called a glomerulus; there is one afferent arterioe for each glomerulus.

Aldosterone A mineralocorticoid produced by the adrenal cortex that promotes sodium and water reabsorption by the kidneys and potassium excretion in urine.

Alkaline Containing more hydroxide ions than hydrogen ions having pH higher than 7.

Allergen An antigen that evokes a hypersensitivity reaction.

Alveolar duct Branch of a respiratory bronchiole around which alveoli and alveolar sacs are arranged.

Alveolar sac A cluster of alveoli that share a common opening.

Amino acid The monomer used to synthesize polypeptide and proteins.

Amnion A thin, protective fetal membrane that develops from the epiblast also called "bag of waters".

Ampulla A sac like dilation of a canal or duct.

Anabolism A energy requiring reactions whereby small molecules are built up into larger ones.

Anemia Condition of the blood in which the number of functional RBC or their hemoglobin content is below normal.

Anterior pituitary Anterior lobe of the pituitary gland also called as adenohypophysis.

Antibody A protein produced by plasma cells in response to a specific antigen.

Aperture An opening or orifice.

Apoptosis Programmed cell death

Arthritis Inflammation of a joint.

Articulation A point of contact between bones, cartilage and bones, teeth and bones.

Asthama Usually allergic reaction characterized by smooth muscle spasms in bronchi resulting in wheezing and difficulty in breathing.

Atresia Abnormal closure of a passage.

Autoregulation A local, automatic adjustment of blood flow in a given region of the body in response to the tissue needs.

B

B cell A lymphocyte that can develop into a clone of antibody-producing plasma cells or memory cells when properly stimulated by a specific region.

Basal ganglia Paired clusters of gray matter deep in each cerebral hemisphere including the globus pallidus, putamen and caudate nucleus.

Basophil A type of WBC characterized by a pale nucleus and larger granules that stain blue-purple with basic dyes.

Bicuspid valve Atrioventricular valve on the left side of the heart.

Bilateral Pertaining to two sites of the body.

Bile A secretion of liver consisting of water, bile salts, bile pigments, cholesterol.

Bilirubin An orange pigment that is one of the end products of hemoglobin break down in the hepatocytes and is excreted as a waste material in the bile.

Blastocyst In the development of an embryo, a hollow ball of cells that consist of a blastocele, trophoblast and inner cell mass.

Blind spot Area in the retina at the end of the optic nerve in which there are no photoreceptors.

Body cavity A space within the body that contains various internal organs.

Bolus A soft, rounded mass, usually food that swallowed.

Buccal pertaining to the cheek or mouth.

Bronchitis Inflammation of the mucous membrane of the bronchial tree.

C

Calcification Deposition of mineral salts.

Calcitonin A hormone produced by parafollicular cells of the thyroid gland that can lower the amount of blood calcium and phosphate by accelerating uptake of calcium and phosphate into bone matrix and by inhibiting bone resorption.

Capillary A microscopic blood vessel located between an arteriole and venule through which materials are exchanged between blood and intestinal fluid.

Cardiac cycle A complete heartbeat consisting of systole and diastole of both atria plus systole and diastole of both ventriacles.

Cataract Loss of transperancy of the lens of the eye.

Cell cycle Growth and division of single cell into two daughter cells.

Cell mediated immunity The component of immunity in which specially sensitized T-lymphocytes attach to antigens to destroy them.

CNS The position of a nervous system that consist of brain and spinal cord.

Centrosome A dense network of small protein fibers near the nucleus of a cell.

Cerebellum The part of the brain lying posterior to the medulla oblongata and pons.

Cerebrum The two hemispheres of the forebrain.

Cervix Neck, any constricted portion of an organ.

Chemotaxis Attraction of phagocytes to microbes by chemical stimulus.

Cholesterol The most abundant steroid in animal tissue, located in cell membreane.

Chronic Applied to a disease that is not acute.

Chyme The semifluid mixture of partly digested food and digestive secretions found in the stomach and small intestine during digestion of meal.

Clone A population of identical cells.

Clotting Process by which blood clot is formed also known as coagulation.

Cochlea A winding, cone shaped tube forming a portion of the inner ear and containing the spiral organ.

Colon The portion of the large intestine consisting of ascending, transverse, descending and sigmoid portions.

Congenital Present at the time of birth.

Conjuctiva The delicate membrane covering the eye boll and lining the eyes.

Cornea The non vascular, transparent fibrous coat through which iris of the eye can be seen.

Corpus The principal part of an organ.

Cranial cavity A subdivision of the dorsal body cavity formed by the cranial bones and containing the bone.

Cytosol Semi fluid portion of cytoplasm in which organelles and inclusions are suspended and solutes are dissolved. Also called as intracellular fluid.

D

Dendrite A neuronal process that carries electrical signals.

Depolarization A reduction of voltage across a plasma membrane.

Dialysis The removal of waste products from blood by diffusion through a selectively permeable membrane.

Diastole In the cardiac cycle, the phase of relaxation or dialation of heart muscle.

Dorsal body cavity Cavity near the dorsal surface of the body that consist of vertebral canal and cranial cavity.

Duodenum The small intestine which connects.stomach and ileum.

E

ECG A recording of the electrical changes that accompany the cardiac cycle that can be detected at the surface of the body.

Emulsification The dispersion of large lipid globules into smaller, uniformly distributed particles in the presence of bile.

Endocrine gland A gland that secretes hormones into intestinal fluid and then the blood.

Eosionphil A type of WBC characterized by granules that stain red or pink with acid dyes.

Epiglottis A large, leaf shaped piece of cartilage lying on top of the larynx.

Epinephrine Hormone secreted by adrenal medulla that produces actions similar to those that result from sympathetic stimulation.

Exocrine gland A gland that secretes its products into ducts that carry secretions into body cavities.

Exhalation Breathing out.

F

Facilitated diffusion Diffusion in which a substance not soluble by itself in lipids diffuses across a selectively permeable membrane with the help of a transporter protein.

Fascia A fibrous membrane covering, supporting and separating muscles.

Fascicle A small bundle or cluster, especially of nerve or muscle fibers(cells).

F cell A cell in the pancreatic islets(islets ,of Langerhans) that secretes pancreatic polypeptide.

Feedback system A sequence of events in which information about the status of situation is continually reported (fed back) to a control center.

Female reproductive cycle General term for the ovarian and uterine cycles, the hormonal changes that accompany them and cyclic changes in the breasts and cervix. Less correctly termed the **menstrual cycle.**

Fertilization Penetration of a secondary oocyte by a sperm cell.

Fibrin An insoluble protein that is essential to blood clotting; formed from fibrinogen by the action of thrombin.

Fimbriae Fingerlike structures, especially the lateral ends of uterine tubes.

Follicle A small secretory sac or cavity; the group of cells that contains a developing oocyte in the ovaries.

Fontanel A fibrous connective tissue membrane filled space where bone formation is not yet complete, especially between the cranial bones of an infant's skull.

Foramen A passage or opening; a communication between two cavities of an organ.

Fundus The part of a hollow organ farthest from the opening.

G

Gallbladder A small pouch, located inferior to the liver, that stores bile and empties by means of the cystic duct.

Gamete A male or female reproductive cell; a sperm or secondary oocyte.

Ganglion A group of neuronal cell bodies.

Genitalia Reproductive organs.

Gestation The period of development from fertilization to birth.

Gland Specialized epithelial cell or cells that secrete substances may be exocrine or endocrine.

Glans penis The slightly enlarged region at the distal end of the penis.

Glomerulus A rounded mass of nerves or blood vessels especially the microscopic tuft of capillaries that is surrounded by the glomerular capsule of each kidney tubule.

Glucocorticoids Hormones secreted by the cortex of the adrenal gland.

Gonod A gland that produces gametes and hormones; the ovary in the female and testis in male.

Gray matter Areas in the central nervous system and ganglia containing neuronal cell bodies, dendrites, unmyelinated axons, axon terminals and neuroglia.

Gustatory Pertainig to taste

Gynecology the branch of medicine dealing with the study and treatment of disorders of female reproductive system.

Gynecomastia Excessive growth of the male mammary glands due to secretion of estrogens by adrenal gland tumor.

H

Hair A thread like structure produced by hair follicles that develops in the dermis.

Hair follicle Structure, composed of epithelium and surrounding the root of a hair from which hair develops.

Hard palate The anterior portion of the roof of the mouth.

Heart A hollow muscular organ lying slightly to the left of the midline of the chest that pumps blood through the cardiovascular system.

Hemetology Study of blood.

Hepatic duct A duct that receives bile from the capillaries. Small hepatic ducts merge to form the larger right and left hepatic ducts that unite to leave the liver as the common hepatic duct.

Hepatocyte A liver cell.

Hernia The protrusion or projection of an organ or part of an organ through a membrane cavity wall, usually abdominal cavity.

Hilus An area, depression or pit where blood vessels and nerves enter or leave an organ. Also called **hilum.**

Hinge joint A synovial joint in which a convex surface of one bone fits into a concave surface of another bone, such as the elbow, knee, ankle and interphalangeal joints.

Histamine Substance found in many cells, especially mast cells, basophils and platelets released when the cells are injured.

Histology Microscopic study of the structure of tissue

Homeostasis The condition in which the body's internal environment remains relatively, constant, within physiological limits.

Horn An area of gray matter in the spinal cord.

Hymen A thin fold of vascularized mucous membrane at the vaginal orifice.

Hypercapnia An abnormal increase in the amount of carbon dioxide in the blood.

Hyperplasia An abnormal increase in the number of normal cells in a tissue or organ, increasing its size.

Hypophyseal pouch An outgrowth of ectoderm from the mouth from which anterior pituitary develops.

Hypophysis Pitutary gland.

Hypoxia Lack of adequate oxygen at the tissue level.

I

Ileum The terminal part of the small intestine.

Immunoglobulin An antibody synthesized by plasma cells derived from B lymphocytes in response to the introduction of the antigen.

Implantation The insertion of a tissue or a part into the body.

Infection Invasion and multiplication of microorganisms in the body tissue.

Infundibulum The stalk like structure that attaches the pituitary gland to the hypothalamus of the brain.

Insulin A hormone produced by the beta cells of a pancreatic islet that decreases the blood glucose level.

Internal ear The inner ear or labyrinth, lying inside the temporal bone, containing the organs of hearing and balance.

Intraocular pressure (IOP) Pressure in the eyeball, produced mainly by the aqueous humor.

Invagination The pushing of the wall of a cavity into the cavity itself.

In vivo In the living body.

Iris The colored portion of the vascular tunic of the eyeball seen through the cornea.

Ischemia A lack of sufficient blood to a body part due to obstruction or constriction of a blood vessel.

Jaundice A condition characterized by yellowness of the skin, the white of the eyes, mucous membrane and body fluids because of the build up of bilurubin.

Jejunum The middle part of the small intestine.

K

Keratin An insoluble protein found in the hair, nails and other keratinized tissues of the epidermis.

Ketone bodies Substances produced primarily during excessive triglyceride catabolism.

Kidney stone A solid mass, usually consisting of calcium oxalate, uric acid or calcium phosphate crystals.

Labia majora Two longitudinal folds of the skin extending downward from mons pubis of the female.

Labia minora Two small folds of mucous membrane lying medial to the labia majora of the female.

Labium A lip like structure.

Lacteal One of the many lymphatic vessels in the villi of the intestine that absorb tryglycerides and other lipid from the digested food.

Lacuna A small hollow space such as found in bones in which osteocytes lie.

Lamellae Concentric rings of hard, calcified matrix found in the compact bone.

Lamina propria The connective tissue layer of mucosa.

Laryngopharynx the inferior portion of the pharynx, extending downward from the level of the hyoid bone.

Larynx The voice box, a short passageway that connects the phrynx with the trachea.

Lesion Any localized, abnormal change in the body tissue.

Leukemia A malignant disease of blood forming tissues characterized by either uncontrolled production or accumulation of immature leukocytes.

Ligand A chemical substance that binds to specific receptor.

Lipase An enzyme that splits fatty acids from glyceraldehydes and phospholipids.

Liver Large organ under diaphragm which is a part of the epigastric region; produces bile and synthesizes most plasma proteins.

Lower limb The appendage attached to pelvic girdle, consisting of thigh, knee, leg, ankle, foot and toes.

Lumbar Region of back and side between the ribs and the pelvis.

Lumen The space within an artery, vein, intestine, renal tubule or tubular structure.

Lymph Fluid confined in the lymphatic vessel and flowing through the lymphatic system until it is returned to the blood.

M

Macrophage Phagocytic cell derived from a monocyte may be fixed or wandering.

Macula A discolored spot or colored area.

Malignant Refering to disease that tend to become worse and cause death.

Mammary gland Modified sweat gland of female that produces milk for nourishment of the young.

Mast cell A cell found in areolar connective tissue that releases histamine, a dialator of small blood vessels, during inflammation.

Medulla An inner layer of an organ, such as the medulla of the kidney.

Medulla oblongata The most inferior part of the brain stem.

Melanin A dark black, brown or yellow pigment found in some parts of body like skin, hair etc.

Metacarpus A collective term for five bones that make up the palm.

Metastasis The spread of cancer to surrounding tissue or to other body sites.

Metatarsus A collective term for five bones located in the foot between the tarsals and phalanges.

Microtubules Rodlike protein filament about 6 nm diameter.

Microglia Neurological cells that carry phagocytosis.

Microvilli Microscopic, fingerlike projections of the plasma membrane of cells that increase surface area of absorption especially in the small intestine.

Midbrain The part of the brain between the pons and diencephalons.

Mole The weight, in grams, of combined atomic weights of the atoms that make up a molecule of a substance.

Mons pubis The rounded, fatty prominence over the pubic symphysis, covered by coarse pubic hairs.

Mucin A protein found in mucus.

Muscle An organ composed of one of the three muscle tissue (skeletal, cardiac or smooth), specialized for contraction to produce voluantary and involuantary action of parts of the body.

Myelin sheath Multilayered lipid and protein covering, formed by schwann cells around axons of many peripheral and CNS neurons.

Myocardium The middle layer of the heart wall, made up cardiac muscle tissue.

N

Nail A hard plate, composed largely of keratin, that develops from the epidermis of the skin to form the protective covering.

Nasal cavity A mucosa lined cavity on either side of the nasal septum that opens onto the face at the external nares.

Neck The part of the body connecting the head and the trunk.

Necrosis A pathological type of cell death that results from disease, injury or lack of blood supply.

Negative feedback The principle governing most control systems; a mechanism of response in which a stimulus initiates actions that reverse or reduce stimulus.

Nephron The functional unit of the kidney.

Nerve **impulse** A wave of depolarization and repolarization that self propagates along the plasma membrane of a neuron.

Neurotransmitter One of a variety of molecules within the axon terminals that are released into synaptic cleft in response to a nerve impulse.

Node of Ranvier A space, along a myelinated axon, between individual schwann cells.

O

Obenes esity Body weight more than 20% above desirable standard due excessive accumulation of fat.

Olfactory Pertaining to smell.

Oncogenes Cancer causing derived from the normal genes.

Oncology Study of tumors.

Ophalmology The study of the structure, function and disease of eye.

Orgasm Sensory or motor events involved in ejaculation for the male.

Osmoreceptor Receptor in the hypothalamus that is sensitive to changes in the blood osmolarity.

Ossicle One of the small bones in the middle ear.

Ossification Formation of bone.

P

Palate The horizontal structure separating the oral and the nasal cavities; the roof of the mouth.

Papilla A small nipple shaped projection or elevation.

Parturition Act of giving birth to young; child birth or delivary.

Pectoral Pertaining to the chest or breast.

Pedicel Footlike structure, on the podocytes of glomerulus.

Periosteum The membrane that covers bone and consists of connective tissue, osteogenic cells and osteoblasts is essential for bone growth, repair and nutrition.

Peristalsis Successive muscular contractions along the wall of a hollow muscular structure.

Pia matter The innermost of the three meninges of the brin and spinal cord.

Pinna The projection part of the external ear composed of elastic cartilage and covered by skin also called the auricle.

Plaque A layer of dense protein on the inside of a plasma membrane. A mass of bacterial cells and other debris that adhere to teeth (dental plaque).

Plasma The extracellular fluid found in the blood vessels.

Pleura The serous membrane that covers lungs and lines the wall of the chest and the diaphragm.

Plexus A network of nerves, veins or lymphatic vessels.

Pons The part of the brain stem that forms a bridge between the medulla oblongata and the midbrain.

Positive stimulus A feedback mechanism in which the response enhances the original

stimulus.

Pregnancy Sequence of events that normally includes fertilization, implantation, embryonic growth and fetal growth and terminates in birth.

Prostate A doughnut shaped gland inferior to urinary bladder that surrounds the superior portion of urethra.

Puberty The time of life during which he secondary sex characters begin to appear and capability for sexual reproduction is possible.

Pulse The rhythmic expansion and elastic recoil of systemic artery after each contraction of the left ventricle.

Pus The liquid product of inflammation containing leukocytes or their remains and debris of dead cells.

Q

QRS wave The deflection waves of an electrocardiogram that represent the onset of ventricular depolarization,

R

Receptor A specialized cell or a distal portion of a neuron that responds to specific sensory modality such as touch, pressure, cold, sound etc.

Renin An enzyme$e released by kidney into the plasma, where it converts angiotensinogen to angiotensinl.

Rete testis The network of ducts in the testis.

Retinal A derivative of vitamin A that functions as the light absorbing portion of the photopigment rhodosin.

Rh factor An inherited antigen on the surface of the red blood cells in Rh+ individuals.

Rod One of two types of photoreceptor in the retina of the eye.

S

Saliva A clear, alkaline somewhat viscous secretion produced mostly by the three pairs of salivary glands.

Sarcomere A contractile unit in a striated muscle fiber cell extending from one Z disc to next Z disc.

Schwann cell A neurological cell of the peripheral nervous system that forms the myelin sheath.

Scrotum A skin covered pouch that contains the testes and their accessory structures.

Secretion Production and release from a cell or a gland of a physiologically active substance.

Semen A fluid discharged at ejaculation by a male that consists of mixture of sperm and secrtion of seminiferous tubules, seminal vesicles etc.

Serum Blood plasma minus its clotting proteins.

Sinus A hollow in a bone or other tissue; a channel for blood; any cavity having narrow opening.

Spasm A sudden, involuntary contraction of large groups of muscles.

Spinal cord A mass of nerve tissue located in the vertebral canal from which 31 pairs of nerves originate.

Spleen Large mass of lymphatic tissue between fundus of the stomach and the diaphragm that functions in the formation of blood cells during early fetal development.

Stasis Stagnation or halt of normal flow of fluids, as blood or urine or of the intestinal contents.

Stimulus Any stress that changes a controlled condition.

Sulcus A groove or depression between compilations of the brain.

Suture An immovable fibrous joint that joins skull bones.

Syndesmosis A slightly movable joint in which articulating ones are united by fibrous connective tissue.

Syndrome A group of signs and symptoms that occur together in a pattern that is characteristic of a particular disease or abnormal condition.

Systemic Affecting the whole body; generalized.

Systole In the cardiac cycle, the phase of contraction of the heart muscle, especially of the ventricles.

T

T cell A lymphocyte that becomes immunocompetent in the thymus and can differentiate into a helper T cell or a cytotaxic T cell, both of which function in cell mediated immunity.

T wave The deflection wave of an electrocardiogram thet represents ventricular repolarization.

Tarsus A collective term for the seven bones of the ankle.

Tendon A white fibrous cord of dense regular connective tissue that attaches muscle to bone.

Testis Male gonad that produces sperm and the hormones restosterone and inhibin. Also called testicle.

Thermoreceptor Sensory receptor that detects changes in temperature.

Thigh The portion of the lower limb between the hip and the knee.

Thrombin The active enzyme formed from prothrombin that converts fibrinogen to fibrin during the formation of a blood clot.

Threshold stimulus Any stimulus strong enough to initiate an action potential or activate a sensory receptor.

Thrombosis The formation of a clot in an unbroken blood vessel, usually a vein.

Thymus A bilobed organ, located in the superior mediastinum posterior to the sternum and between the lungs, in which T cell develop immunocompetence.

Tonsil An aggregation of large lymphatic nodules embedded in the mucous membrane of the throat.

Trabecula Irregular latticework of thin plates of spongy bone.

Trauma An injury, either physical wound or psychic disorder, caused by external agent or any physical force or emotional shock.

U

Umblical cord The long, ropelike structure containing the umbilical arteries and veins that connect fetus to the placenta.

Upper limb The appendage attached at the shoulder girdle, consisting of the arm, forearm, wrist, hand and fingers.

Urine The fluid produced by the kidneys that contains waste and excess materials; excreted from the body through the urethra.

Urology The specialized branch of medicine that deals with the structure, function and diseases of the male and female reproductive system.

Uvula A soft, fleshy mass, especially the V shaped pendent part, descending from the soft palate.

V

Vagina A muscular, tubular organ that leads from the uterus to the vestibule, situated between the urinary bladder and the rectum of the female.

Vasa recta Extensions of the efferent arteriole of juxamedullary nephron that run alongside the loop of the nephron in the medullary region of the kidney.

Vasectomy A means of sterilization of males in which portion of each ductus deferens is removed.

Vasodialation An increase in the size of the lumen of a blood vessel caused by relaxation of the smooth muscle in the vessel.

Ventral Pertaining to the anterior or front side of the body, opposite of dorsal.

Vesicle A small bladder or sac containing liquid.

Vestibule A small space or cavity at the beginning of a canal, especially the inner ear, larynx, mouth, nose and vagina.

Visceral Pertaining to the organs or to the covering of an organ.

Vitamin An organic molecule necessary in trace amounts that act as catalyst in normal metabolic processes in the body.

W

Wave summation The increased strength of muscle contraction that results when muscle action potentials occur one after another in rapid succession.

White matter Aggregations or bundles of myelinated and unmyelinated axons located in the brain and the spinal cord.

Y

Yolk sac An extraembryonic membrane, transfers nutrients to the embryo, is a source of blood cells and helps to prevent desiccation of the embryo.

Z

Zygote The single cell resulting from union of male and female gametes; the fertilized ovum.

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